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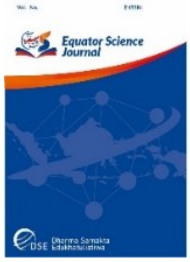

The Application of The Discovery Learning Model in Wave Concepts to Enhance High School Students' Cognitive and Problem-Solving Skills

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ABSTRACT
This study aims to implement the Discovery Learning model to improve the cognitive abilities and problem-solving skills of high school students on the topic of waves. The research method used is pre-experimental with a one-group pretest-posttest design. Research instruments include objective tests to measure cognitive abilities and essay tests to measure problem-solving skills. The results show that the application of the Discovery Learning model provides a significant contribution to student learning outcomes. Cognitive ability improved with an average N-Gain value of 0.76, which is classified in the High category. Meanwhile, problem-solving skills also increased with an average N-Gain value of 0.79, also in the High category. Overall, the Discovery Learning model is effective in improving the mastery of cognitive concepts; however, more intensive guidance and continuous habituation are required to optimize students' systematic problem-solving skills.

INTRODUCTION

Students' cognitive abilities have become a key focus in various educational policies in Indonesia. Government Regulation No. 19 of 2005 on National Education Standards emphasizes that the learning process must develop three main domains: cognitive, affective, and psychomotor. In the cognitive domain, students are not only expected to memorize information but also to understand, apply, analyze, evaluate, and create knowledge. This aligns with Ministry of Education and Culture Regulation No. 20

of 2016 on Graduate Competency Standards (SKL), which emphasizes the importance of logical, analytical, critical, and creative thinking as part of Higher Order Thinking Skills (HOTS).

An overview of students' cognitive abilities can also be seen in the National Assessment report conducted by the Ministry of Education, Culture, Research, and Technology through the Minimum Competency Assessment (AKM). The AKM is designed to assess reading literacy and numeracy in both scientific and socio-cultural contexts, with a focus on reasoning, analyzing information, and problem-solving, rather than mere memorization (Kemendikbudristek, 2021). The results of the AKM analysis indicate that the majority of test items remain at the lower-order thinking skill levels, including C1 (remembering), C2 (understanding), and C3 (application). Only about 16% of the test items measure higher-order thinking skills (HOTS), which include C4 (analyzing), C5 (evaluating), and C6 (creating) (Yapis Dompu, 2022). This indicates that the majority of students are still focused on basic cognitive abilities, while their analytical and evaluative skills have not developed optimally. Additionally, the results of the Trends in International Mathematics and Science Study (TIMSS) 2019 also show that as many as 74% of Indonesian students are only able to solve problems that measure lower-order thinking skills, while only about 5% are able to solve problems requiring a deeper conceptual understanding (Mullis et al., 2020). These findings indicate that high school students still focus more on lower-order thinking skills, while their mastery of higher-order thinking skills remains limited, including in physics education.

Education plays a vital role in driving a nation's progress, particularly in preparing human resources capable of addressing 21st-century challenges. The educational process is not only focused on mastering knowledge but also on changing students' mindsets and shaping their character as indicators of individual development (Syahputra, 2024). In the 21st century, education requires students to master a variety of skills relevant to the changing times, including: (1) critical thinking and problem-solving skills, (2) communication and collaboration skills, (3) creativity and innovation skills, (4) technological and communication literacy, (5) contextual learning skills, and (6) information and media literacy (Jayadi et al., 2020). Among these skills, problem-solving ability is one of the main learning objectives because it plays a crucial role in preparing a generation that addresses the demands of the 21st century (Kurniawati et al., 2019). Education must ensure that students possess skills aligned with the current and future demands, such as critical thinking and problem-solving abilities (Nabilah, 2020). Furthermore, Davita and Pujiastuti (2020) state that problem-solving is a crucial aspect of learning because it enables students to apply their knowledge and skills as a foundation for addressing everyday challenges. Similarly, Umamah and Andi (2020) explain that physics, as a branch of science, emphasizes scientific and technological approaches, thereby encouraging students to discover and construct their own knowledge. Therefore, the learning process needs to be directed toward improving problem-solving skills (Rahmana et al., 2021).

To improve the quality of education in addressing the 21st century challenges, the Indonesian government has implemented the Merdeka Curriculum. This curriculum emphasizes the strengthening of the Graduate Profile—a set of competencies aligned with the Graduate Competency Standards (SKL) and grounded in the values of Pancasila (Hamzah et al., 2022). The implementation of this Graduate Profile is expected to strengthen character while developing students' competencies, including enhancing problem-solving skills as well as sensitivity and a critical attitude toward various issues in the surrounding environment (Hernawan & Mulyati, 2023).

However, various studies indicate the learning process did not fully meet expectations yet. This is evident in the still-low levels of students' cognitive abilities and problem-solving skills. The Direct Instruction (DI) model, which is still widely used, tends to place less emphasis on the process of knowledge construction, causing students to focus more on rote memorization without deep understanding (Ismaya et al., 2015). Additionally, students' habit of solving problems similar to previous examples is another cause of low problem-solving skills, as it lacks the challenge of addressing issues requiring more complex analysis and solution strategies (Wijayanti et al., 2023). Without strong problem-solving skills, the learning process leads to a decline in conceptual mastery (Fitriyani et al., 2025). Umamah and Andi (2020) state that students still do not understand the steps involved in solving a problem, causing them to struggle in meeting the Minimum Competency Criteria (MCC) in physics. This situation is influenced by a lack of exploration of students' problem-solving abilities.

Furthermore, our preliminary study found a similar issue. The result of an interview with a physics teacher in Bandung indicates that many 11th-grade students still lack adequate cognitive and problem-solving skills regarding wave-related material. According to the physics teacher, this situation stems from students' tendency to view physics as a difficult subject and to focus solely on memorizing formulas, which makes it hard for them to visualize and understand the concepts, particularly in the wave unit.

Based on the results of the literature review, preliminary study, and interviews with the physics teacher, the data show that students' cognitive and problem-solving skills remain relatively low. Additionally, research by Azizah et al. (2017) also indicates that students face various difficulties in physics learning, such as understanding concepts and formulas, interpreting equations in problems, analyzing graphs or diagrams, and drawing conclusions. The findings of Sigit and Gustina (2025) indicate that students' errors most frequently occur at the stages of translation and conceptual understanding, thereby highlighting the importance of instructional models that can foster thinking and problem-solving skills. Hence, an alternative learning process that could enhance cognitive skills and problem solving skills is needed.

To address various issues in the physics learning process, it is essential to implement learning models that shift the approach from teacher-centered to student-centered (Herviana et al., 2020). Other research further emphasizes the importance of using learning models that can optimally facilitate students' learning needs (Rahmana et al., 2021). In optimizing this process, the use of the discovery learning model serves as a solution to address students' low problem-solving abilities. This model focuses on a learning process that directly confronts students with issues related to their experiences through scientific steps, ranging from the observation stage to drawing conclusions. Through the application of this model, students' science process skills can be developed because they are challenged to solve problems that trigger various questions and opinions. Overall, discovery learning plays a role in encouraging students to be more active, courageous in asking questions, and critical in their thinking, thereby enhancing their science process skills (Sinaga, 2020, as cited in Mokodompit, Buhungo, & Odja, 2024). Wave concepts require a solid conceptual understanding as well as appropriate instructional presentation. The use of handouts can help enhance student engagement and understanding, thereby supporting the quality of learning (Ismiyatun et al., 2024). Therefore, instructional models such as discovery learning are needed to foster students' thinking and problem-solving skills.

Hence, this study aims (1) to determine the improvement in students' cognitive abilities regarding wave-related material following the implementation of the discovery learning model and (2) to determine the improvement in students' problem-solving abilities regarding wave-related material following the implementation of the discovery learning model.

METHOD

This study aims to examine improvements in students' cognitive abilities and problem-solving skills following the implementation of discovery learning. This study employs a pre-experimental study with a one-group pretest-posttest design. Creswell (2009) explains that by using a pre-experimental one-group pretest-posttest design, the researcher studies a single group and applies the treatment without a control group to compare against the experimental group. In this design, students will take a pretest, then receive the treatment, and finally take a posttest. The research design structure can be seen in Table 1.

Table 1. One-group Pretest-Posttest Design

Pretest	Treatment	Posttest
O_1	X	O_2

Notes:

O_1= Pre-test before the intervention

X = Implementation of the discovery learning model

O_2 = Post-test after the intervention

The population in this study consists of all 11th-grade students at a public high school in Bandung. The sample was selected using convenience sampling, which involves choosing participants based on ease of access and availability (Creswell, 2012). The sample comprised Class 11-2 with 35 students, as this class met the criteria and was able to participate in the entire designed learning sequence.

The research variables consist of independent and dependent variables. The independent variable in this study is the application of the discovery learning model to waves, while the dependent variables are students' cognitive abilities and problem-solving skills, measured before and after the intervention. The determination of these variables aims to examine the direct effect of the applied learning model on students' learning outcomes.

The research was conducted over two sessions (equivalent to four class periods during school hours) within a single Grade XI class. Before the first session began, students were given a pretest. This was followed by a lesson covering the fundamentals of Waves, including wave quantities, types of waves, and wave properties. The second session focused on Sound Waves. Once the entire learning process was completed, students were given a posttest in the final meeting.

In this research, the discovery learning model is utilized. According to Jerome Bruner (1961), discovery learning is not merely a method with rigid procedural steps, but rather an approach to organizing knowledge so that students are capable of independent discovery. Bruner emphasizes the mental processes that allow students to assimilate subject matter into their cognitive structures through a series of cognitive processes. In educational literature referencing Bruner's framework, the operational stages commonly applied in discovery learning (and frequently cited in educational research) include the following steps presented in Table 2.

Table 2. Stages of The Discovery Learning Model

Stage	Description
Stimulation	The teacher provides a stimulus in the form of a problem, question, or situation designed to pique students' curiosity and initiate the learning process. This stimulus serves as the primary trigger to motivate students to seek out new knowledge.
Problem Statement	Students are guided to clearly identify and formulate the problem to be solved. This process encourages students to exercise their critical thinking skills in recognizing and defining specific issues.
Data Collection	Students actively seek and gather information, facts, data, or evidence relevant to the problem at hand. This data collection can be conducted through observations, experiments, interviews, literature reviews, or other methods.
Data Processing	The data and information obtained are then processed and analyzed to identify patterns, relationships, or tentative solutions. Students learn to organize and interpret information logically.

Stage	Description
Verification	The results of the analysis are tested for accuracy through experiments, presentations, discussions, or reflection. Students verify the validity of their hypotheses or the information gathered in the previous stages.
Generalization	Students draw conclusions regarding the knowledge or concepts discovered based on the investigation and verification process. These conclusions can then be applied to other situations, representing a deep understanding of the concept.

Therefore, the improvement in students' cognitive abilities and problem-solving skills was analyzed based on their pretest and posttest scores. Cognitive abilities were measured using a validated multiple-choice test with a "right-only" scoring technique, in which correct answers were scored as 1 and incorrect answers as 0. Cognitive abilities were assessed according to the Bloom's Taxonomy revised by Anderson & Kratwhol (2001), including the remembering aspect (C1), the understanding aspect (C2), the applying aspect (C3), and the analysing aspect (C4). Meanwhile, problem-solving skills were measured through a validated essay test with a score range of 0 to 4 for each item. The scores obtained from the pretest and posttest results were then analyzed to determine the improvement in students' abilities. For problem-solving, the framework followed George Polya (1973).

RESULTS AND DISCUSSIONS

Cognitive Ability

Improvement in the cognitive abilities of 11th-grade students were measured using a multiple-choice test administered before (pretest) and after (posttest) the learning process. The average pretest and posttest scores, as well as the N-Gain values for the students' cognitive abilities are presented in Table 3.

Table 3. Average Pre-test and Post-test Scores and N-Gain in Cognitive Ability

<Pretest>	<Posttest>	<g>	Category
57,57	89,85	0,76	High

The results of the analysis in table 3 show that students' average cognitive scores increased, by 32.28 points. This improvement is supported by an average N-Gain value of 0.76, which, according to Hake's criteria, falls into the "High" category (Hake, 2002). This indicates that the use of the Discovery Learning model is highly effective in helping students understand abstract concepts in the waves topic.

Improvements in students' cognitive abilities across each aspect can be determined from the test scores obtained by students on each item in the pretest and posttest. There are four aspects investigated in this study, including remembering aspect (C1), the understanding aspect (C2), the applying aspect (C3), and the analysing aspect (C4) (Anderson & Krathwol, 2001). A comparison of the average pretest and posttest scores for each cognitive aspect in the observed Grade XI class is presented in Table 4.

Table 4. Average Pretest and Posttest Scores and N-Gain for Each Aspect of Cognitive Ability

Aspect	<Pretest>	<Posttest>	<g>	Category
Remembering (C1)	57,143	85,714	0,67	Moderate
Understanding (C2)	61,714	90,571	0,75	High
Applying (C3)	56	93,571	0,85	High
Analyzing (C4)	47,429	84,571	0,71	High

Table 4 shows that the implementation of the Discovery Learning model has a positive impact on improving all aspects of students' cognitive abilities, ranging from remembering (C1) to analyzing (C4). Overall, there was an increase in average scores between the pretest and posttest results for each indicator. The effectiveness of this improvement was measured using the N-Gain value, where the application aspect (C3) achieved the highest value of 0.85, which falls into the high category. This indicates that the discovery learning model plays a significant role in training students to use learned concepts to solve problems. In line with this, the understanding (C2) and analysis (C4) aspects also demonstrated significant effectiveness with N-Gain scores of 0.75 and 0.71, respectively, both falling within the high category. Meanwhile, the remembering aspect (C1) achieved an N-Gain score of 0.67, which falls into the moderate category. Although it falls into the moderate category, this result still indicates a strengthening of students' memory retention regarding the basic terms or definitions of the material taught through this learning model.

The results of the analysis indicate that improvements in students' cognitive abilities varied across different aspects. The remembering aspect (C1) fell into the moderate category with an N-Gain score of 0.67. Although this was the lowest compared to the other aspects, this achievement still reflects a significant improvement. The relatively modest improvement in this aspect was influenced by the students' high initial ability levels prior to the intervention, which limited the scope for further improvement. Furthermore, in line with Sudarman (2008), in active learning, students' focus tends to shift from merely recalling information toward information processing and problem-solving, leading to more significant development in higher-order cognitive aspects. This finding is also consistent with Siahaan (2017), who states that variations in gain scores are influenced by students' initial conceptual mastery.

The understanding aspect (C2) showed improvement in the high category with an N-Gain score of 0.75. This improvement was supported by the stimulation and problem statement stages, which encouraged students to understand the problems through the worksheets. These results are consistent with Wahyuni's (2016) study, which stated that Discovery Learning is effective in improving conceptual understanding because students actively construct knowledge through the processes of observation and problem identification. Furthermore, this finding is supported by Piaget's learning theory, which emphasizes the importance of assimilation and accommodation in forming understanding. The use of PhET interactive simulations also contributes to visualizing abstract concepts, consistent with Finkelstein et al. (2005), who state that simulations help students construct more accurate mental models.

Furthermore, the application (C3) and analysis (C4) aspects fell into the high category, with N-Gain values of 0.85 and 0.71, respectively. This improvement was influenced by the data collection, data processing, and verification stages in the Discovery Learning model, which actively engage students in collecting, processing, and verifying data. Additionally, Hidayat et al. (2017) noted that the data processing and verification processes encourage students to test hypotheses, thereby deepening their understanding. Analytical skills are also strengthened through exploration activities and pattern discovery, as stated by Prasetyo & Syam (2017), and in line with Anderson & Krathwohl (2001), who emphasize that analytical skills involve the process of breaking down and connecting concepts.

Overall, these findings indicate that the Discovery Learning model is effective in enhancing students' cognitive abilities, particularly in higher-order thinking. Learning that emphasizes exploration, analysis, and verification has proven superior to conventional models in helping students understand abstract concepts such as waves more deeply.

Problem Solving Ability

The improvement in students' problem-solving skills was measured using an essay-based test administered before (pretest) and after (posttest) the learning process. The average pretest and posttest scores, as well as the N-Gain values for students' problem-solving skills are presented in Table 5.

Table 5. Average Pretest and Posttest Scores and N-Gain in Problem-Solving Skills

<Pretest>	<Posttest>	<g>	Category
23,43	84,37	0,79	High

Table 5 shows that the average score for students' problem-solving skills increased by 60.94 points. This improvement is supported by an average N-Gain value of 0.79, which, according to Hake's criteria, falls into the "High" category (Hake, 2002). This indicates that the use of the Discovery Learning model is highly effective in helping students understand abstract concepts in the waves topic.

Improvements in students' problem-solving skills across all aspects can be observed through the test scores they achieved on each item in the pretest and posttest. There are four stages of problem-solving thinking covered in this study, namely understanding the problem, formulating a strategy, implementing the strategy, and evaluating the results. A comparison of the average pretest and posttest scores for each aspect of problem-solving ability in the observed Grade XI class is shown in the Table 6..

Table 6. Average Pretest and Posttest Scores and N-Gain for Each Aspect of Problem-Solving Ability

Aspect	<Pretest>	<Posttest>	<g>	Category
Understanding the Problem	25,63	89,08	0,85	High
Devising a Plan	19,27	83,05	0,79	High
Carrying Out the Plan	19,27	79,81	0,75	High
Looking Back/Evaluating the Solution	13,29	79,15	0,79	High

Table 6 shows the average pretest and posttest scores, as well as the N-Gain values, for each aspect of problem-solving ability among students. Based on the table, it can be observed that all aspects of problem-solving showed varying degrees of improvement following the intervention. The "Understanding the Problem" aspect showed the highest achievement, both in the pretest score of 25.63 and the posttest score of 89.08. Meanwhile, the "Evaluating Results" aspect had the lowest posttest score compared to the other aspects, at 79.15. Nevertheless, overall, this data indicates that students had the strongest initial ability in understanding the problem compared to formulating strategies or evaluating results.

When examined in terms of improvement effectiveness through the N-Gain value, the Problem-Understanding aspect achieved a score of 0.85, which falls into the High category. This indicates that the application of the Discovery Learning model was highly effective in helping students identify the information and core issues presented. Consistent with these findings, the other three aspects also showed significant improvement and fell into the High category: the Formulating Strategies aspect with an N-Gain score of 0.79, the Implementing Strategies aspect at 0.75, and the Evaluating Results aspect at 0.76. Achievements in these three aspects indicate that the use of the Discovery Learning model aided by PhET simulations is capable of training students to formulate systematic solution steps, perform calculations accurately, and verify the results obtained.

Overall, the improvement in problem-solving skills in the observed Grade XI class shows very positive progress, with the "High" category dominating every aspect. This is reinforced by the total average N-Gain score of 0.79, which, according to Hake's criteria, falls into the High category. These findings demonstrate that integrating the Discovery Learning model into the waves topic can transform students' procedural skills into more measurable and focused competencies.

The analysis results indicate that the students' problem-solving ability in understanding the problem aspect is categorized as high, with an N-Gain score of 0.85. This improvement was facilitated through the stimulation and problem statement stages, where students were guided to identify known information and formulate the problem. This high achievement suggests that the initial stages of Discovery Learning are effective in training students to understand the structure of a problem before proceeding to calculations. This finding is consistent with Gormally et al. (2009), who state that the inquiry process can enhance students' ability to map problems systematically, and is further supported by Polya's theory (1973), which emphasizes that understanding the problem is the most crucial step in problem-solving.

In the devising a plan aspect, students' abilities also fell into the high category with an N-Gain score of 0.79. This skill was cultivated during the data collection and data processing stages, where students designed their solution steps and determined the appropriate approach. These results align with Hardiawan (2019), who states that discovery-based learning can enhance students' ability to design solutions because they are accustomed to developing ideas from the early stages. Furthermore, this ability is closely linked to the understanding aspect (C2), as a solid grasp of concepts helps students select relevant physics principles.

Furthermore, the carrying out the plan aspect is in the high category with an N-Gain score of 0.75. This improvement occurred through the data collection and data processing stages, where students gathered and processed data based on the strategies they had formulated. This result is supported by Heller et al. (1992), who state that the primary difficulty for students in physics problem-solving lies in the ability to accurately connect concepts with mathematical procedures.

In the looking back aspect, students' abilities are also in the high category with an N-Gain score of 0.79, which was practiced through the verification stage. At this stage, students re-check both the results and the solution process. Nonetheless, the achievement in this aspect is relatively lower compared to understanding the problem, as students tend to stop once they obtain a final answer without performing a deep evaluation. This aligns with Polya (1973), who states that the looking back stage is often neglected. However, the implementation of Discovery Learning still contributes to habituating students to verify through discussion and reflection, thereby helping to improve precision in evaluating results.

CONCLUSION AND SUGGESTION

A study using the discovery learning model to examine students' cognitive abilities and problem-solving skills regarding wave concepts has been completed. Several conclusions were drawn, as outlined in response to the following research questions: (1) Students' cognitive abilities improved by 0.76 in the high category following the implementation of the discovery learning model on wave concepts. (2) The improvement in students' problem-solving skills after applying the discovery learning model to the topic of waves showed a high-level increase of 0.79. This research is also expected to provide significant practical benefits. For educators, this study offers a new innovation in the learning process by applying the Discovery Learning model to wave mechanics to enhance the cognitive abilities and problem-solving skills of high school students. For students, this research is intended to train and improve their cognitive and problem-solving capacities following the instruction. For schools, these findings can serve as an evaluation tool to continuously develop effective teaching strategies and learning models for students.

Based on the research conducted, the following are the researchers' recommendations, which are intended to serve as a reference for the implementation or development of similar research in the future: (1) Use a research design that includes a control group to strengthen the analysis of changes in cognitive abilities and problem-solving skills following the implementation of the discovery learning model. (2) The application of the discovery learning model can be tested on other physics topics, particularly abstract concepts that can be explored through direct or indirect experiments, as well as a wider variety of contextual phenomena. (3) Strictly manage time allocation, especially during the Data Processing and Verification stages, to ensure students have sufficient time to practice problem-solving skills independently. (4) Allocate more time for discussions and Q&A sessions so that students can identify more phenomena in their daily lives.

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