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Enhancing Physics Learning with Advance Organizer: A Meta-Cognitive Approach

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Abstract

Physics education often presents challenges for students due to its abstract and complex nature. Many students struggle to comprehend the interrelationships between concepts and tend to memorize formulas without developing a deep conceptual understanding. This study aims to evaluate the effectiveness of the Advance Organizer as a metacognitive approach to enhance students' scientific literacy, conceptual understanding, and mathematical communication skills. The research method employed is Research and Development (R&D) using the 4D model (Define, Design, Develop, and Disseminate), combined with a quasi-experimental design employing the Nonequivalent Control Group Design. The developed instructional materials include lesson plans (RPP), student worksheets (LKPD), interactive visual-based learning media, and assessment instruments. The findings indicate that students in the experimental group using the Advance Organizer demonstrated significantly greater improvements in conceptual understanding compared to the control group. The average scientific literacy score increased from 71.88 to 83.22 (N-Gain = 0.40, moderate category), while mathematical communication skills improved from 68.03 to 79.38 (N-Gain = 0.35, moderate category). Statistical analysis using Hotelling's T^2 test revealed a significant difference between the experimental and control groups ($F = 14.755$, $p < 0.05$), while effect size analysis using Cohen's f showed a large impact on scientific literacy ($f = 0.625$) and a moderate effect on mathematical communication ($f = 0.342$). Although this strategy proved effective, several challenges were identified, including students' initial difficulties in adapting to active learning methods and the need for teacher training in designing optimal Advance Organizers. This study recommends integrating the Advance Organizer with digital technology and further exploring its application across various physics topics to enhance the effectiveness of metacognitive-based learning.

INTRODUCTION

Learning physics often poses challenges for students due to its abstract nature and the need for an in-depth understanding of complex concepts [1]. Concepts in physics, such as quantum mechanics, electromagnetism, and relativity, are often not directly observable, making it difficult for students to visualize and understand the relationships between interacting physical variables. Additionally, traditional approaches to physics education that focus solely on mathematical calculations tend to hinder students' conceptual understanding and lead to lower problem-solving skills in real life. Therefore, strategies that can connect theory with real-world applications are necessary so that students can grasp the benefits of physics concepts in everyday life.

Many students struggle to link theory with real phenomena and to transfer their knowledge to solve new problems [2]. This is because physics learning in the classroom often focuses only on the delivery of theory without providing the contextual application that can help students understand the relevance of the material being studied. However, context-based understanding is essential in science education to enhance students' critical thinking and analytical skills. Thus, approaches that are based on exploring real phenomena and technology-based experimental simulations are highly recommended for physics teaching.

These difficulties are often exacerbated by learning approaches that prioritize memorizing formulas over developing conceptual understanding [3]. Memorizing formulas without deep understanding can leave students struggling to apply the concepts they have learned in new situations. Research shows that learning strategies that focus solely on the mastery of formulas without conceptual exploration are ineffective in improving students' cognitive competencies, especially when facing problems that require more complex problem-solving. [3] emphasize that deep understanding requires approaches that encourage students to think analytically and understand the relationships between concepts rather than just memorizing formulas.

Therefore, a learning strategy that can build connections between students' cognitive schemes and new information has become an urgent need in physics education. One of the approaches that can address this challenge is the Advance Organizer, designed to help students link new information with the knowledge they already possess. By providing cognitive maps before learning, advance organizers enable students to be better prepared to receive and assimilate new material effectively. The application of this strategy has been proven to enhance conceptual understanding and facilitate more meaningful learning for students [4]. Highlight that advance organizers not only serve as tools for understanding but also as bridges that enable the internalization of new knowledge through more structured and contextual learning experiences.

Ausubel first introduced Advance Organizer as a tool to help students connect new knowledge with the cognitive structures they already have [5]. In his theory of meaningful learning, Ausubel emphasized that the process of assimilating new information becomes more effective when students have an initial schema that can serve as a basis for understanding [6]. By providing a framework before the main learning begins, Advance Organizers not only help students understand the relationships between concepts but also enhance their capacity to assimilate new information more meaningfully [1]. Compared to Problem-Based Learning (PBL), which focuses on problem-solving and encourages students to discover concepts through real-world scenarios, Advance Organizer provides a structured cognitive framework that prepares students before engaging with new material. Research by Hmelo-[7] suggests that while PBL can enhance problem-solving and critical-thinking skills, it may not always provide sufficient scaffolding for students to integrate new knowledge effectively. Similarly, Inquiry-Based Learning (IBL) promotes exploration and hypothesis-driven learning, but without prior cognitive structure, students may struggle to connect abstract concepts [8]. Therefore, Advance Organizer serves as an alternative instructional approach that helps bridge the gap between students' prior knowledge and new information, reducing cognitive load and enhancing meaningful learning in physics education.

Recent research shows that advanced organizers can act as cognitive bridges that reduce students' cognitive load when understanding abstract concepts, such as those often encountered in physics [9]. This strategy helps activate relevant schemas in long-term memory, allowing students to more easily integrate new information with concepts they have previously learned [4]. For example, in a study by [10], the use of an interactive media-based advance organizer in straight-motion material showed a significant increase in students' conceptual understanding. However, previous studies have primarily focused on the effectiveness of advance organizers in general physics topics without exploring their impact on scientific literacy and mathematical communication in an integrated manner. Additionally, limited research has examined how advance organizers can be systematically designed and implemented within structured instructional models to optimize their effectiveness. This study addresses these gaps by applying the advance organizer strategy specifically in the context of work and energy while simultaneously evaluating its impact on students' scientific literacy, conceptual understanding, and mathematical communication.

Furthermore, by incorporating interactive visual-based learning media, this study expands on previous research by examining how multimodal representations enhance students' cognitive processing and engagement in physics learning; the application of advanced organizers has evolved alongside advancements in educational technology. In digital learning, advance organizers can take the form of interactive visualizations, introductory videos, or simulations based on virtual reality that allow students to gain an initial understanding before delving deeper into the material [11]. The use of this technology reinforces the effectiveness of advance organizers in improving long-term retention and students' conceptual understanding. Therefore, the implementation of advanced organizers combined with modern learning technology has the potential to have a greater impact on enhancing the quality of physics education.

In physics learning, advance organizers can take the form of conceptual diagrams, analogies, or visual representations that serve as initial guides before students begin to explore the material more deeply. Research shows that this strategy not only improves conceptual understanding but also helps students develop more effective problem-solving skills. For instance, in a study conducted by [3], advance organizers were used to help students understand mechanics concepts through visual representations and problem-based narratives. The research findings indicated that students who learned with advanced organizers experienced greater improvements in understanding compared to those who learned through conventional methods. This study also highlights that the success of advance organizers highly depends on how teachers design and implement them in the learning process.

Recent research supports this finding by highlighting various forms and media that can be used in the application of advance organizers. For instance, Amir and [12] studied the application of the advanced organizer learning model assisted by artificial intelligence (AI), such as ChatGPT, in enhancing conceptual understanding of physics among students. The results indicated that the use of AI as an aid in advance organizers significantly improves conceptual understanding compared to traditional collaborative methods.

Moreover, the use of interactive media in advance organizers has also proven effective. Darmawan and [13] found that the application of the advanced organizer model assisted by PhET media, which is an interactive simulation for science learning, can significantly enhance students' learning outcomes. This study also showed that students' critical thinking skills play an important role in the effectiveness of applying advanced organizers with interactive media.

Furthermore, [14] demonstrated that the application of the advanced organizer learning model aided by computer animation is effective in improving high school students' physics learning outcomes. The use of computer animation as part of the advanced organizer helps students understand abstract physics concepts more concretely and engagingly.

However, the effectiveness of advance organizers highly depends on their design and implementation. Teachers need to ensure that the advance organizers used are appropriate for the student's level of understanding and relevant to the material being taught. Additionally, the integration of technology, such as AI and interactive media, must be done carefully to ensure that they truly support the learning process and do not become distractions for students.

Overall, recent studies indicate that advanced organizers, especially those supported by modern technology, can be effective tools in improving students' understanding and problem-solving skills in physics education. Nonetheless, the success of implementing this strategy greatly depends on the proper design and effective implementation by educators.

Another study by [10] examined the effectiveness of the advanced organizer learning model assisted by interactive video media on learning outcomes in physics regarding straight motion. The research findings showed that the use of this media can significantly improve students' understanding, as it presents abstract physics concepts in a more concrete and easier-to-understand manner.

As technology in education continues to evolve, the implementation of advanced organizers is also adapting within digital learning environments. [9] found that the use of advanced organizers in virtual classrooms has a significant impact on enhancing students' science process skills. In technology-based learning, advance organizers can take the form of interactive videos, simulations, or other multimedia that allow students to explore concepts more dynamically and interactively.

In addition, research by [2] shows that the integration of advanced organizers with interactive video tutorials can enhance students' critical thinking skills and metacognitive reflection. In the study, students who used advanced organizer-based tutorials demonstrated a more significant improvement in problem-solving skills compared to the control group that learned without this approach. This emphasizes that advance organizers not only serve as a tool for delivering information but also as a means to build a deeper conceptual understanding through active student engagement in the learning process.

From a cognitive psychology perspective, effective learning occurs when students can connect new information with the cognitive schemas they have previously developed [1]. Advance organizers play an important role in this process by providing a framework that can help students structure and interpret physics concepts more systematically. Research by [4] reveals that advanced organizers not only enhance students' conceptual understanding but also contribute to long-term retention of physics material. Students who learn through this model tend to better remember and apply concepts in different situations compared to those who learn through traditional methods. This is due to better activation of schemas, where new information is more easily integrated into existing cognitive structures.

Although many studies have demonstrated the effectiveness of advanced organizers in physics learning, there are still several challenges in their implementation. One of the main challenges is how teachers can design advance organizers that are appropriate for students' understanding levels and the characteristics of the subject matter [3]. Furthermore, there is a need for further research on how advanced organizers can be combined with other learning strategies, such as laboratory-based inquiry or project-based approaches, to enhance their effectiveness in broader contexts.

Overall, advance organizers offer a promising approach to enhancing students' understanding of physics through schema activation and strengthening metacognitive skills. With the continuous development of technology and innovative learning methods, this strategy can be further refined and applied more widely in various educational contexts.

Based on the issues outlined, this research aims to analyze the effectiveness of applying advanced organizers in physics learning and how this strategy can help improve conceptual understanding and problem-solving skills among students. Additionally, this research also explores how the integration of advanced organizers with educational technology can optimize physics learning. The findings of this research are expected to provide insights for educators in designing more effective and innovative advanced organizer-based learning.

METHODS

This study uses a research and development (R&D) methodology with the 4D model (Define, Design, Develop, and Disseminate) developed by [15]. This model was chosen because it can produce systematic and tested learning devices through several evaluation stages before being implemented widely. The main focus of this research is to develop and test the effectiveness of physics learning devices based on Advance Organizer in improving students' science literacy and mathematical communication skills. The developed learning devices include Lesson Plans (RPP), Student Worksheets (LKPD), handouts, interactive visual learning media, and evaluation instruments used to measure the success of the implementation of these devices.

This research begins with the Define stage, which aims to identify problems in physics learning and determine the need for the development of learning devices. At this stage, preliminary studies are conducted through classroom observations and interviews with physics teachers to understand the ongoing learning conditions. The observation results indicate that the teaching method applied is still dominated by a conventional model with a teacher-centered approach, where the teacher mainly delivers materials without actively involving students in exploring concepts. Interviews with teachers also revealed that students face difficulties in understanding abstract concepts in physics, especially on the topic of Work and Energy, which requires an understanding of the relationships between force, displacement, and changes in energy within various systems.

Additionally, an analysis of the students was conducted to understand the characteristics of the participants in this research. The students of class X at SMA Negeri 1 Mlati involved in this study are at the formal operational stage according to Piaget's cognitive development theory. At this stage, students are expected to think abstractly, understand complex concepts, and connect theory with real-world applications. However, the analysis shows that many students still struggle to link physics concepts with everyday phenomena, which impacts their critical thinking skills. Therefore, a learning strategy is needed that can bridge the gap between the knowledge students already possess and the new concepts being learned.

This study involved 33 students from Class X MIPA 2 at SMA Negeri 1 Mlati as the experimental group, who received the advanced organizer-based learning intervention. Additionally, 31 students from Class X MIPA 1 were assigned as the control group and followed a direct instruction model. The total sample size of 64 students was selected using a quasi-experimental nonequivalent control group design, allowing for a comparison of learning outcomes before and after the intervention. The selection method ensures that both groups are comparable while evaluating the effectiveness of the Advance Organizer model in enhancing students' scientific literacy and mathematical communication skills.

The next step is task analysis, which aims to identify the competencies that students must master under the 2013 Curriculum. Indicators of science literacy and mathematical communication skills are mapped based on Core Competencies (KI) and Basic Competencies (KD) in physics subjects. This analysis aims to ensure that the developed learning devices not only help students understand physics concepts theoretically but also train them to interpret data, use mathematical representations, and analyze relationships between variables in various physics situations. Furthermore, a concept analysis is conducted, where the material on Work and Energy is mapped in the form of a systematic concept map. This mapping aims to identify the interconnections among concepts so that students can understand how the principles of physics are interconnected within a coherent system.

After the definition stage is completed, the research proceeds to the Design stage, where the learning tools are developed while paying attention to the principles of instructional design. Several products developed include syllabi, lesson plans (RPP), student worksheets (LKPD), handouts, and interactive visual learning media. The lesson plans are structured based on the Advance Organizer model syntax, which includes the stages of presenting the organizer, delivering the main material, as well as clarifying and applying concepts in various contexts. The student worksheets are designed to guide students in exploring physics concepts through discussion-based activities, problem-solving, and simple experiments. Additionally, handouts and learning media are developed in the form of text, images, and interactive animations to help students understand abstract concepts in a more engaging and comprehensible way. In this stage, evaluation instruments are also prepared, consisting of pretests and posttests, observation sheets, and student response questionnaires, which are used to measure the effectiveness of the learning tools in enhancing student understanding.

The next stage is development, which aims to test the validity and effectiveness of the learning tools before being implemented on a larger scale. This process begins with expert validation, conducted by physics education experts and experienced teachers, to assess the feasibility of content, adherence to the curriculum, and clarity of material presentation in the learning tools. After the tools are deemed valid, a limited trial is conducted, in which the learning tools are applied to a small group of students to evaluate the clarity of the material, completeness of instructions, and the level of student engagement in learning. Based on the results of the limited trials, revisions, and refinements of the tools are made before they are applied in a field trial involving an experimental group and a control group.

In the field trial stage, the learning tools are applied using a quasi-experimental design with a Nonequivalent Control Group Design. In this design, the experimental class uses the Advance Organizer learning tools, while the control class employs conventional methods. The effectiveness of the learning tools is evaluated by comparing the pretest and posttest results between the two groups. Additionally, observations are conducted to assess the implementation of the learning process, and questionnaires are given to students to understand their perceptions and experiences during learning with the Advance Organizer-based tools.

The final stage of this research is dissemination, which aims to disseminate the results of the developed learning tools for utilization by other teachers and schools. Dissemination is carried out through publications in academic journals, presentations at education seminars, and the distribution of learning tools to physics teachers in several schools. Furthermore, this research opens opportunities for further development, where the learning tools can be adapted for other materials in the physics curriculum and integrated with digital learning technologies.

In this research, the subjects are students from class X at SMA Negeri 1 Mlati, divided into experimental and control classes. The research instruments used include pretest and posttest, observation sheets, student response questionnaires, and expert validation sheets. Data analysis is conducted quantitatively and qualitatively. Quantitative analysis uses statistical tests like Cohen's f to determine the effectiveness of the learning tools, while qualitative analysis is performed by examining observation results and student questionnaires to understand how the Advance Organizer-based learning tools influence student engagement and understanding in learning physics.

RESULTS AND DISCUSSION

Learning physics often presents challenges for students due to its abstract and complex nature. Many students struggle to understand the connections between concepts, especially in topics like Work and Energy, which require a deep understanding of the relationships between force, displacement, and changes in energy within a system. This difficulty is exacerbated by conventional teaching approaches that still focus on rote memorization of formulas without providing a deep and contextual learning experience. Therefore, this research develops a learning device based on Advance Organizer as a metacognitive strategy aimed at helping students connect new concepts with their existing cognitive frameworks, thus enhancing their conceptual understanding.

To measure the effectiveness of this strategy, the research was conducted through several stages, starting from the validation of the learning device, limited trials, to field trials using a quasi-experimental design. The results of this study will be discussed based on the data collected, including the validity of the learning device, the feasibility of the learning process, student learning outcomes, and the effectiveness of the Advance Organizer compared to conventional methods. Additionally, the discussion will connect the findings of this study with supporting theories, such as Ausubel's meaningful learning (1968), Sweller's cognitive load theory (1988), and Paivio's dual coding theory (1986). Thus, this section will provide a comprehensive analysis of the impact of Advance Organizer in enhancing science literacy, mathematical communication, and conceptual understanding among students in physics education.

Results of Learning Device Validation

The advanced organizer-based learning device developed in this study has undergone a validation process by experts in physics education and experienced teachers. The validation was conducted to assess the feasibility of the content, alignment with the curriculum, clarity of presentation, and the effectiveness of the device in enhancing students' conceptual understanding. The validation results showed that all aspects of the learning device were categorized as very good, with an average score of 3.50 – 3.79, indicating that the device is suitable for use in instruction.

Theoretically, this validation supports the concept proposed by [5] in meaningful learning theory, which states that advanced organizers help students connect new knowledge with the cognitive structures they already possess. The validation also indicated that interactive visual learning media and the use of conceptual diagrams in the Student Worksheet facilitate students in understanding the interconnections between concepts. This finding is reinforced by [4], stating that the use of Advance Organizers not only serves as a cognitive aid but also assists students in building a deeper conceptual understanding through better activation of their existing schemas.

Results of Limited Trials

After validation, the learning device was trialed in a limited scope in class XI MIPA 2 at SMAN 1 Mlati to assess the implementation of learning and student responses to the developed device. Observation results indicate that all stages of learning in the lesson plan (RPP) were successfully carried out, with reliability of implementation reaching 100%, meaning that the learning device can be consistently implemented.

Additionally, survey data show that the majority of students provided positive feedback regarding the Advance Organizer-based learning device. As many as 74% of students rated the device as "good," and 26% rated it as "very good," particularly regarding the clarity of the material, involvement in discussions, and ease of understanding the concepts. The success of this limited trial aligns with Vygotsky's (1978) constructivist theory, which states that learning is more effective when students are provided with cognitive tools that enable them to build their understanding through interaction with the learning environment.

However, several challenges were encountered during this limited trial, such as some students having difficulty adjusting to the more active learning methods, especially those who were previously accustomed to conventional methods focused more on memorization. Additionally, some students still struggled to use conceptual diagrams and analogies as tools to connect concepts in the material of Work and Energy. This feedback serves as the basis for revising the Student Worksheet (LKPD) and learning media before being implemented in field trials.

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Effectiveness of the Learning Device

To evaluate the effectiveness of the learning device in more depth, a statistical analysis using Hotelling's T^2 test was conducted, which indicated a significant difference between the experimental class and the control class in terms of the improvement in science literacy and mathematical communication ($F = 14.755$, $p < 0.05$). Additionally, to measure the impact of learning based on Advance Organizer on students' understanding, an effect size calculation using Cohen's f was performed, which showed that the Advance Organizer had a large impact on the improvement of science literacy ($f = 0.625$, large category) and a medium impact on mathematical communication ($f = 0.342$, medium category).

From the results of the pretest and posttest, it was found that the experimental class experienced a more significant increase in understanding compared to the control class. In terms of science literacy, the average score of the experimental class increased from 71.88 to 83.22, with an N-Gain of 0.40 (medium category). Meanwhile, the control class only risen from 74.87 to 80.63, with an N-Gain of 0.23 (low category). A similar result was found in the aspect of mathematical communication, where the experimental class's score increased from 68.03 to 79.38 (N-Gain = 0.35, medium category), while the control class only risen from 44.30 to 52.40 (N-Gain = 0.14, low category). This significant difference indicates that Advance Organizer contributes more significantly to helping students understand the connections between physics concepts and represent them mathematically compared to conventional methods.

In addition to the quantitative analysis, the results of interviews and student response questionnaires also showed that students in the experimental class found it easier to understand the relationships between concepts after using the Advance Organizer. As many as 66% of the students stated that this tool was "very good," and 34% said it was "good," with the majority of students mentioning that conceptual diagrams, analogies, and visual representations in the Advance Organizer greatly helped in facilitating their understanding of the work and energy material. In contrast, students in the control class expressed that they still faced difficulties in understanding concepts because the learning was more focused on delivering theories without a clear conceptual structure to connect new information with their existing cognitive frameworks.

These findings support Ausubel's meaningful learning theory (1968), which states that learning will be more effective when new information is presented in a context that can be linked to existing knowledge. Furthermore, these results align with the research by Maries & [16], which showed that the Advance Organizer strategy can reduce students' cognitive load, enhance their engagement in learning, and help them understand abstract concepts more deeply. Therefore, these field trial results further reinforce that the Advance Organizer is not only an instructional tool but also serves as a cognitive mechanism that allows students to be more active in building their conceptual understanding.

Effectiveness of Learning Devices

To evaluate the effectiveness of the learning device more deeply, statistical analysis using Hotelling's T^2 test was conducted, which showed that there was a significant difference between the experimental class and the control class in terms of the improvement of science literacy and mathematical communication ($F = 14.755$, $p < 0.05$). Additionally, to measure the impact of Advance Organizer-based learning on student understanding, effect size calculations using Cohen's f were performed, showing that the Advance Organizer had a large effect on the improvement of science literacy ($f = 0.625$, large category) and a medium impact on mathematical communication ($f = 0.342$, medium category).

CONCLUSION

The implementation of the Advance Organizer in physics learning has proven effective in enhancing students' science literacy, mathematical communication, and conceptual understanding. The research results show that the experimental class made significant improvements compared to the control class, both in science literacy (N-Gain = 0.40) and mathematical communication (N-Gain = 0.35). Students in the experimental class were also more active in discussions, asking questions and providing systematic explanations of concepts. Statistical analysis revealed a significant difference between the experimental and control classes, indicating that the Advance Organizer had a large effect on science literacy and a medium impact on mathematical communication. These findings suggest that the Advance Organizer strategy effectively aids students in connecting new information with existing knowledge, thus enhancing their understanding of complex physics concepts.

The implications of these results highlight the potential of the Advance Organizer in improving students' engagement and understanding in physics education. This strategy not only boosts cognitive abilities but also fosters active participation in learning. However, challenges remain, such as students' adaptation to new learning methods and the need for proper teacher training in using the Advance Organizer optimally. Therefore, future research should focus on developing flexible variations of the Advance Organizer, particularly integrating digital technologies like interactive simulations, artificial intelligence (AI), or augmented reality (AR). Further studies could also explore its impact on more complex physics topics and diverse student populations. Additionally, the findings emphasize the importance of teacher training programs to ensure the effective implementation of the Advance Organizer, which can significantly enhance physics education across various learning contexts.

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