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Exploring Computational Thinking in Physics Education: An AI-Driven Analysis of Decomposition and Abstraction Challenges

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Abstract:
The importance of Computational Thinking (CT) ability is not only one of the essential competencies of the 21st century but also a foundation for solving complex problems and building high-level thinking skills. This study aims to explore the computational thinking (CT) ability of new students in the physics education study program on vector material. The research method used is descriptive qualitative, involving eight new physics education students at the Islamic University of Madura as respondents. Data were collected through a test instrument, and each question refers to the computational thinking indicator (Decomposition, abstraction, algorithm, and generalization). The results of data analysis show that the indicators of students' CT abilities on a scale of 4 consist of decomposition with an average value of 3.125, abstraction 2.438, algorithm 2.125, and generalization 1.687. Based on the study results, it can be concluded that the CT skills of first-year students at the Islamic University of Madura on vector material are included in the moderate category. Several indicators of CT abilities are still challenging for students, especially in developing algorithms and generalizations. Therefore, further research is needed to improve students' computational thinking abilities to face the challenges of the 21st century.

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INTRODUCTION

The development of technology and information in the 21st century requires individuals to have high-level thinking skills, such as systematic, critical, logical, and computational thinking (CT) abilities. CT's capabilities are essential skills that students must have in the 21st century because, in the problem-solving process, the focus is not only on solving the problem but also on how the problem is solved (Kang, 2024). CT capability is one of the important demands in the 21st century because it can help individuals understand the complexity of the modern world and adapt to changes that occur quickly and dynamically (Jamna et al., 2022).

Research on CT capabilities is increasingly recognized as an essential skill to face the rapid development of technology and the era of digitalization (Ramadhani & Yahfizham, 2024; Yokuş & Kahramanoglu, 2022). CT ability is considered a new literacy that must be possessed by students and college students because this concept is relevant in computer science and extends to various other fields of science, including physics. CT's ability in physics material provides a deep understanding of physics concepts, especially in analyzing phenomena and simulations. By mastering CT, physics students can integrate computational techniques to understand the relationship between variables and solve problems efficiently (Herlina, 2024).

However, the adoption of CT in physics learning still faces various challenges (Gambrell & Brewe, 2023). Many educators do not yet understand how to integrate CT practices into learning, so they only focus on transferring knowledge rather than encouraging active student involvement in scientific practices. As a result, students' CT abilities, especially in physics, are still relatively low. This can be seen from several previous studies that show that students often have difficulty applying computational concepts to solve physics problems (Jamalludin et al., 2022; Hani Sulsilah, 2023; Handayani et al., 2023).

Research on CT exploration in physics material has been conducted at the junior high school (SMP) level on optics material (Jamalludin et al., 2022). Hani Sulsilah (2023) says that vector material is more kinematic than material on temperature and heat (Amrizaldi et al., 2024). However, research on CT capability exploration at the college level has not been conducted. Therefore, it is necessary to conduct research on CT capability exploration at the college level, especially on vector material. Vector material is an important basic concept in physics because it is the foundation for understanding many advanced concepts such as mechanics, electromagnetism, and fluid dynamics (Putri, 2023). Most of the physics concepts covered in basic physics courses at the college level are represented by vectors (Husni et al., 2021).

Some reasons include educators tending to teach science as a collection of content that must be memorized rather than encouraging computational thinking. Students, especially in physics, need to have CT skills. The novelty of this study lies in its focus on CT skills at the college level, providing insights into how CT can be effectively embedded in higher education physics curricula. The findings are expected to contribute to developing innovative teaching strategies and learning media that enhance computational thinking in physics education.

This study explores students' CT ability in solving physics problems on vector materials at the Islamic University of Madura in first-year Physics Education Study Program students. This study argues that integrating CT into physics education at the college level is essential to develop students' problem-solving and analytical thinking skills. The results of this study are expected to contribute to understanding how CT can be integrated into physics learning at the college level, as well as being a reference for choosing more effective learning methods and media. The results of this study will provide valuable recommendations for educators, helping them implement CT-based learning strategies that encourage deeper engagement and better learning outcomes in physics education.

RESEARCH METHOD

This research employs a descriptive qualitative approach, focusing on first-year Physics Education Study Program students at the Islamic University of Madura. The study involved eight first-year students as respondents, aiming to explore their computational thinking (CT) abilities in solving physics problems related to vector material. The research was designed to assess students' problem-solving skills and understanding of CT indicators through structured essay tests. The primary data collection technique utilized in this study was an essay test. The test instrument consisted of two physics problems on vector material, each containing four sub-questions that assessed CT indicators:

decomposition, abstraction, algorithm, and generalization (Crismono, 2023; Donthu et al., 2021; Gao et al., 2022). This instrument was adopted from Nisa and had a validity coefficient of 0.85. The instrument was tested using the Rasch Model through Winstep Software to ensure its reliability further. The validity analysis was conducted based on trial results with class XI students, confirming that the test items were valid and suitable for measuring CT abilities.

The collected data were analyzed qualitatively using the Miles and Huberman (1984) model, which includes three main stages: data reduction, data presentation, and conclusion drawing. Data reduction involved filtering and organizing relevant information from student responses, followed by data presentation in an organized manner to identify patterns and key findings. The final stage involved drawing conclusions based on the analyzed data and providing insights into the CT abilities of the students in solving physics vector problems.

RESULT AND DISCUSSION

Results

Dominance of Decomposition Indicators in Problem Solving

The research results show that the decomposition indicator is the most dominant CT indicator compared to other indicators. With an average score of 3.12 on a scale of 4 or around 33.6% of the total score, students can divide problems into smaller parts well. In solving problems, students systematically break down the information provided to find a solution, as in the case of solving vectors F1 and F2 in Cartesian coordinates. However, some errors were still found in drawing vector directions or determining angles. This finding shows that students' ability to break down problems into smaller parts is quite good, supported by their experience in classifying material concepts from the start of learning. Data on students' abilities in completing tests based on the CT indicators achieved can be seen from the completeness of the CT ability indicators in Figure 1.

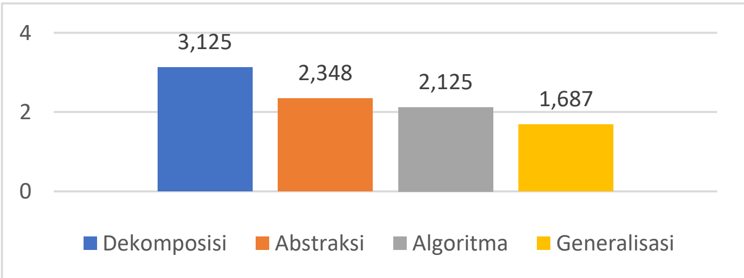

Figure 1. Average CT Ability Results

Figure 1 show that decomposition is the most dominant CT indicator compared to other types of indicators with an average score of 3.12 on a scale of 4 or a percentage of 33.6% of the total value. In the first problem question that focuses on the decomposition indicator, respondents generally answered with systematic steps, starting with breaking down the information used to find solutions to solve the problem, such as in question one in the first problem, describing the vectors F1 and F 2and describe the vectors F1 and F 2on Cartesian coordinates correctly.

However, some students are wrong in drawing directions or in determining angles. The stages carried out by these respondents are included in the decomposition stage, where respondents separate the whole problem into several simpler parts. This decomposition indicator is relatively easy for respondents, as seen from the percentage in Figure 1 (b), the student's score is relatively high compared to other indicators. This shows that the student's ability to divide problems into simpler parts can be solved well by the students. This is very possible because students have learned from the beginning the initial steps on how to classify everyday life materials based on material concepts.

Low Generalization Ability in Compiling General Patterns

The generalization indicator was the biggest challenge for students in this study, with an average score of 1.68 or only 17.4%, making it the indicator with the lowest score. Many students have difficulty identifying general patterns and applying the same solutions in various problem contexts. This shows that students are still unable to connect the concepts they have learned with different situations, so they have difficulty finding systematic patterns in the data provided.

One of the main causes of this low generalization ability is students' study habits which are more oriented towards memorization than conceptual understanding. Students tend to remember formulas and solution procedures without understanding the basic principles underlying them. As a result, when they are faced with problems that require the application of concepts in different situations, they have difficulty adapting their solution strategies. A lack of in-depth understanding of basic concepts also exacerbates this problem, so students tend not to be able to see the relationship between various problems that have similar patterns.

These findings confirm that more effective learning strategies are needed to improve students' generalization abilities in computational thinking. Project-based approaches and interactive simulations can be the right solution because these methods allow students to explore various problem scenarios and discover applicable patterns more independently. Apart from that, the application of learning methods such as problem-based learning (PBL) and collaborative discussions can also help students develop a deeper understanding of the concepts they are studying so that they are better prepared to apply solution patterns to various types of problems.

The low generalization ability of students in constructing general patterns indicates a gap between deep conceptual understanding and the application of concepts in broader contexts. This reflects the need for a learning approach that emphasizes understanding concepts and their application in various situations rather than memorizing formulas and procedures. More interactive and problem-based learning strategies, such as Project-Based Learning and interactive simulations, can effectively improve students' generalization abilities. This approach allows students to identify patterns in various problem contexts. It encourages them to be more active in linking concepts they have learned to new situations to develop more holistic and applicable computational thinking skills.

Abstraction Indicators Experience Challenges in Identifying Relevant Information

The abstraction indicator has an average score of 2.125 with a percentage of 26.2%, indicating that most students succeeded in identifying important information in the problem, such as force magnitudes and angles. Success in this indicator reflects students' ability to classify important information to develop effective solutions. However, there are still some challenges in filtering out truly relevant information and ignoring unnecessary elements. This difficulty shows that even though students understand the importance of abstraction in problem-solving, further practice is still needed to improve their skills in selecting the most important and strategic information.

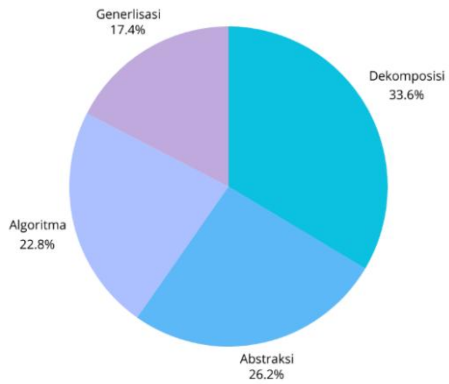

Figure 2. Average CT Ability Percentage

Figure 2 show that the information from each existing condition is recorded one by one so that it is simpler and easier to understand because elements that are not needed to find a solution have been removed. This stage is an indicator of abstraction, which focuses on strategic steps in formulating a problem by identifying and extracting important relevant information and discarding unnecessary ones. Based on Figures 1(a) and 1(b), the abstraction indicator has an average score of 2.125 with a percentage of 26.2%, which shows that most of the respondents succeeded in identifying important things that need to be considered in the question, regarding known information such as the magnitude of force F1, F 2and angles. This step shows that respondents have implemented the abstraction stage quite well.

Difficulty in Preparing Appropriate Algorithmic Steps

At the algorithm stage, it was found that although students were able to write the correct formula, many of them immediately entered the values without first analyzing the context of the problem. This approach causes errors in the application of concepts, especially when students calculate resultant force without projecting vectors on the x and y axes using trigonometric functions. Errors in preparing these solution steps show that students still do not have a deep understanding of the logical sequence in solving a problem based on computational thinking.

With an average score of 2.125 or 22.8%, the algorithm indicators in this research show that many students have not been able to systematically develop solution steps. One of the main causes of this difficulty is a lack of understanding of the basic concepts underlying calculations. Apart from that, study habits that are more oriented towards memorizing formulas rather than understanding the concepts are also a factor that contributes to students' weak algorithmic skills. As a result, students tend to immediately apply the formula without considering whether the steps they take are appropriate to the context of the problem given.

This difficulty reflects the need for improvements in learning strategies, especially in increasing students' understanding of the structure of systematic problem-solving. One solution that can be implemented is to use a project-based approach and interactive simulation, which allows students to understand how a formula is applied in various problem contexts. In addition, exercises that emphasize gradual problem-solving, such as problem-based learning (PBL), can help students develop a more structured and logical algorithmic thinking pattern.

Discussion

The percentage of abstraction indicators that are quite high indicates that students' ability to classify important information to solve problems and formulate solutions effectively is quite good. This also reflects increased critical thinking skills, which are the key to solving problems more efficiently (Erma Nurdaningsih et al., 2023). This achievement supports the results of the previous decomposition indicator, where students demonstrated the ability to separate problems into simple components, which were then continued by filtering important information through abstraction (Hidayah et al., 2024; Ataman et al., 2024).

The next step is to develop a solution plan, followed by the calculation process needed to obtain a solution to the problem. At this stage, most respondents have successfully written the formula correctly, but some fill in the formula section incorrectly, although some of the final results are correct. At this stage, some students immediately write the formula and enter the values in the problem without first analyzing the formula according to the context of the problem (Hashanah, 2024; Maisuroh et al., 2024). Students tend to immediately write the formula and enter the values in the problem without first analyzing the formula according to the context of the problem. This may be due to the assumptions in textbook problems, which often ignore the need for students to understand the underlying physics concepts. As a result, it can cause confusion and misapplication of the formula. Several respondents' writing of the formula shows that the steps they took were still not completely correct. This indicates that the respondents have carried out the algorithm stage, although imperfect (Arifin et al., 2024).

At the algorithm stage, most students directly enter the value of the force components into the vector resultant formula without first taking the correct steps, such as breaking down the vector on the x and y axes and projecting them separately using trigonometric functions (Abdullah & Java, 2024; Saharani et al., 2024). Before calculating the resultant force, students should project the force on the x and y axes by multiplying the force components by a factor or according to the given angle. This error shows a lack of understanding in the steps of the algorithm stage, where they skip the data processing process first and immediately apply the final formula to find the resultant force (Mamun, 2024).

Algorithm skills still need to be improved because students still have problems compiling structured and efficient solution steps (Amrizaldi et al., 2024). Students' abilities in this indicator are sufficient, but the second lowest of the other indicators, with an average score of 2.125 percent of 22.8%. This shows that students have been unable to write down the solution steps properly, so the problem is unresolved. One respondent did not provide an answer at all (Munawwaroh, 2024). Students have difficulty completing the solution steps due to internal and external factors. Internal factors include being in a hurry when working, not understanding the questions, not being careful in answering, not mastering the concept of the material, and not being confident in their answers (Sulistya, 2021). Meanwhile, external factors include conditions that are not conducive when doing the test, such as noise and being disturbed by friends who invite you to talk or play (Heru & Bali, 2024).

Generalization skills also need to be improved. In the last stage, respondents showed difficulties in the generalization indicator process. Many respondents still have not done the generalization stage; it can be seen that this problem is caused by respondents not understanding the questions, which makes it difficult for the average respondent to determine the general form of different problems (Putri, 2024). Analysis of the answers shows that their ability in this generalization indicator is relatively low; this can be seen in Figures 1 (a) and 1 (b) with an average score of 1.68 with a percentage of 17.4%, which has the lowest value compared to other indicators (Faisol et al., 2024). Students struggle to identify general patterns or apply solutions to similar problems in different contexts. Some students cannot find systematic patterns in the data or situations in the questions. This is often due to a lack of deep understanding of the basic concepts. Students memorize formulas or facts without understanding the underlying principles, making it difficult to relate the knowledge to different situations or contexts (Anggraini, 2023).

This finding is consistent with previous research stating that developing Computational Thinking skills requires intensive practice and special guidance. Innovative learning approaches, such as the use of interactive simulations and the application of relevant case studies, can help students gain a better understanding of the concept and application of Computational Thinking, especially algorithms and generalizations, which are still relatively low (Kresnadi et al., 2023). In line with 2024, this study emphasizes that improving computational thinking requires practical methods and specific guidance. It highlights the importance of collaborative learning and structured discussions in helping students master CT indicators, including abstraction and algorithms (Kang, 2024). Project-based learning on computational thinking skills in physics, especially in decomposition, abstraction, and simulation, is designed to train students to solve physics problems analytically and logically. This approach effectively improves students' computational thinking skills in a structured manner (Handayani et al., 2022).

Improvement can be made by providing more varied exercises, including blended learning, problem-based learning, simulations, and project-based experiments. Technology, such as computer simulations, can also support students' understanding of difficult concepts, especially those related to algorithms and abstractions. This study is an important contribution to understanding Computational Thinking (CT) abilities among physics education students, especially in vector material. The study results indicate that although students' CT abilities are in the moderate category, there are still significant challenges in developing algorithmic and generalization abilities.

CONCLUSION

First-year students of the physics education study program have Computational Thinking (CT) abilities on vector material that can be categorized as quite good, especially in the decomposition and abstraction stages. Students' computational thinking abilities on vector material show a varied distribution, with the decomposition indicator as the highest ability (33.6%) and generalization as the lowest ability (17.4%). This reflects the need for a comprehensive and adaptive learning approach that focuses on problem analysis and abstraction, generalization, and algorithms. Therefore, efforts are needed to improve students' CT abilities in designing systematic solution steps and improving generalization abilities. Students can be better trained to develop more balanced computational thinking abilities across indicators through learning strategies such as project-based learning, interactive simulations, and problem-based approaches. Thus, students can be more effective in solving physics problems with a computational approach.

This study has limitations in the relatively small number of respondents and only focuses on vector material, so the results cannot necessarily be generalized to other physics materials. Further research is expected to involve a larger number of respondents from various universities to obtain a more representative picture of the CT abilities of physics students at the college level. In addition, further research is needed to discuss learning strategies that can strengthen students' CT abilities, especially in the algorithm and generalization indicators. More sophisticated learning technology, such as AI applications in physics learning, can also be the focus of further research to explore its effect on improving CT skills.

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