

Analysis of Students' Concept Understanding Using the STEM Integrated Cognitive Conflict Model

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Abstract: This study aims to analyze the conceptual understanding and needs of teaching materials based on the STEM integrated cognitive conflict model. The study was conducted in three high schools in Padang City (SMAN 4, SMAN 9, and SMAN 11) using a survey method with a qualitative descriptive approach. Data were collected through a diagnostic test of 15 kinematics and dynamics questions, which were classified into four categories of conceptual understanding: understand, doubt, misconception, and do not know the concept. The results showed that the average student conceptual understanding was below 50%, with the highest misconception in dynamics material (41.82%) and the highest conceptual ignorance in kinematics material (51.91%). It was found that the learning approach was still teacher-centered, not encouraging active concept construction. The integration of the cognitive conflict model with the STEM approach is recommended to improve students' conceptual understanding, because it is able to stimulate cognitive reflection through conflict situations and link concepts to real-world applications. These findings indicate that the model has great potential to overcome misconceptions and build a more meaningful understanding of physics.

Keywords: Cognitive conflict model; Conceptual understanding; STEM

Introduction

The implementation of the Kurikulum Merdeka in physics learning emphasizes concept mastery as the main indicator in assessing students' learning achievements (Fatimah & Muamar, 2024; Fransiska et al., 2022; Pranata et al., 2022). Conceptual understanding is key in helping students solve physics problems (Atika et al., 2023; Saputra & Mustika, 2022), because they are required to be able to apply the concepts they have learned in various contexts (Azizah et al., 2017; Wulandari et al., 2023; Utami & Khotimah, 2023). Therefore, physics learning will be meaningful if students have the ability to understand and integrate physics concepts in depth (Capriconia & Mufit, 2022; Hunaidah et al., 2022; Saudah et al., 2019).

Good conceptual understanding allows students not only to memorize theories but also to be able to apply these concepts in solving various real problems (Widia et al., 2020). A well-understood concept allows students to associate new knowledge with previously acquired knowledge. However, in reality, many students have difficulty understanding science concepts, especially abstract and complex material (Mvula, 2020; Nikat et al., 2022). Students' conceptual understanding of physics concepts in Indonesia is still very lacking, one of the causes is students who have the wrong concept or misconception in understanding the concept (Hasanah et al., 2020; Mirnawati et al., 2021).

Misconception is defined as an initial understanding that deviates from the scientific concept agreed upon by experts (Aini et al., 2023; Pratiwi et al.,

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2023). This inaccuracy of understanding, if not immediately corrected, will form a continuous erroneous knowledge structure, thus hindering students' ability to integrate and communicate various physics concepts coherently (Mukhlisa, 2021; Muzakki et al., 2023). In general, the steps used to help overcome misconceptions are to find the misconceptions made by students, try to find the causes of students' misconceptions, and find the right treatment solutions to overcome them (Entino et al., 2021).

The STEM approach integrates the basic principles of science, technology, engineering, and mathematics through scientific practices oriented towards problem solving (Le et al., 2023). Students are directed to develop investigative questions, conduct empirical exploration, and engage in technical design processes as an effort to solve contextual problems. Thus, the integration of STEM in the learning process has proven effective in improving students' conceptual understanding (Asrizal et al., 2023). The STEM approach is designed as a holistic and contextual learning approach (Ortiz-Revilla et al., 2022) with the aim of preparing learners to have an innovative mindset and be able to face real-life challenges critically and creatively (Giamellaro & Siegel, 2018; Lavi et al., 2021; Ningkaula et al., 2021). The implementation of the STEM approach is feasible because it is able to strengthen cross-disciplinary integration that emphasizes design engineering, critical thinking skills, and essential problem-solving abilities (Agudelo Rodríguez et al., 2024; Roberts et al., 2022).

Integration of the STEM approach with the cognitive conflict model can improve students' conceptual understanding (Putri & Saehana, 2021). The cognitive conflict model is a model designed to stimulate conceptual change by introducing situations that conflict with students' initial understanding. By creating cognitive conflict, students are encouraged to re-examine their concepts (Ilahi et al., 2021) and adjust them to correct scientific knowledge (Mufit et al., 2023). This process encourages students to reflect on their understanding and reconstruct concepts in accordance with applicable scientific theories. The stages of the cognitive conflict model emphasize changes in students' concepts, from incorrect initial concepts (misconceptions) to correct concepts so that cognitive conflict learning has a higher influence on physics learning, especially students' conceptual understanding and improvement of misconceptions.

Research has shown that the cognitive conflict model is effective in improving students' understanding of scientific concepts across a range of science topics. For example, research revealed that cognitive conflict can correct misconceptions that occur in students in certain topics. However, research that integrates cognitive

conflict with the STEM approach is still limited. In fact, this integration has the potential to provide more holistic learning, combining theoretical understanding with practical application in the real world (Annisa et al., 2024).

Several previous studies have shown that the cognitive conflict model is effective in improving conceptual understanding, but its integration with the STEM approach is still relatively under-explored. Research by Arifin et al. (2023) shows that the application of the STEM approach can improve students' ability to solve problems creatively, but does not discuss how the cognitive conflict model can be applied to deepen conceptual understanding in this context.

Previous studies have also noted that there are still gaps regarding the application of the cognitive conflict model in STEM learning, especially in the context of secondary education. Several studies on the application of the cognitive conflict model in science learning are generally limited to certain areas and have not fully integrated the technical and mathematical aspects of the STEM approach holistically (Bahtiar et al., 2022). This shows that there is still room for more in-depth research on how the cognitive conflict model can help students understand concepts in science, technology, engineering, and mathematics in a more integrated and applicable manner.

Therefore, this study focuses on preliminary research to analyze the application of the integrated cognitive conflict model with the STEM approach, which is expected to provide new contributions in improving students' conceptual understanding.

Method

The research method in this study is to design research with the Plomp development model. The Plomp model consists of 3 steps, namely the preliminary research phase, prototyping phase, and assessment phase. The research conducted is a preliminary research to see the students' understanding of the concept. The data used are in the form of needs analysis and literature review. The instruments used for the needs analysis are teacher interview sheets and student concept understanding test sheets in the form of diagnostic test.

Data on preliminary research conducted on teachers, namely by interview. Interviews were conducted with teachers of SMAN 4, SMAN 9, and SMAN 11 with each represented by 2 teachers in each school. Interview questions regarding learning methods, learning models, and learning outcomes. Data on student needs analysis were obtained from diagnostic tests to test students' conceptual understanding. This test was conducted in grade 11 with representatives

from each 2 classes in each school, namely SMAN 4 (72 students), SMAN 9 (72 students), and SMAN 11 (72 students). Diagnostic tests on students were conducted to determine students' conceptual understanding. The diagnostic test conducted included 15 fill-in questions

divided into 4 categories of understanding, namely conceptual understanding, less confident conceptual understanding, misconceptions, and do not know the concept. The explanation of the 4 categories of conceptual understanding can be seen in table 1.

Table 1. Concept Understanding Division Category

Concept Understanding Level	Code	Question Criteria	
		Objective questions	Belief
Understand the Concept	UC	Correct	Sure
Understand the Concept Not Sure	UCNS	Correct	Not Sure
Misconception	M	Wrong	Sure
Don't know the concept	DKC	Wrong	Not Sure

Table 1 is a division of the conceptual understanding categories used in this study. The questions taken for the conceptual understanding test on the kinematics and dynamics material were made based

on the question indicators of the material. The question grid for the kinematics and dynamics material is presented in Table 2.

Table 2. Question Grid

Material	Sub Material	Question Indicator	Number of Question
Kinematics	Uniform straight motion	Students are able to understand the concept of uniform linear motion	1 and 2
	Uniformly accelerated linear motion (vertical motion)	Students are able to understand the concept of uniformly accelerated linear motion (vertical motion)	3 and 4
	Uniformly accelerated linear motion (free fall motion)	Students are able to understand the concept of uniformly accelerated linear motion (free fall motion)	5 and 6
	Circular motion	Students are able to understand the concept of circular motion	7 and 8
	Parabolic motion	Students are able to understand the concept of parabolic motion	9 and 10
Dynamics	Newton's laws	Students are able to understand the relationship between force and motion in Newton's laws.	11, 12, 13, 14, and 15

Table 2 is the distribution of question indicators in the sub-material that becomes the grid in making questions. The next stage is to process data from the diagnostic tests that have been carried out. The test results are then converted into percentages with the following scale:

$$S = \frac{N}{R} \times 100\% \tag{1}$$

Information:

S : Diagnostic test score

R : Number of correct answers

N : Maximum test score

The average score for each value obtained is divided into criteria as shown in table 3.

Table 3. Criteria for Students' Conceptual Understanding

Interval	Criteria
86%-100%	Very high
76%-85%	High
60%-75%	Medium
55%-59%	Low
≤ 54%	Very low

Result and Discussion

This research was conducted by interviewing teachers and giving diagnostic tests to students. Interviews and research were conducted in 3 high schools in Padang City, namely SMAN 4, SMAN 9, and SMAN 11. Interviews were conducted with 6 teachers, each represented by 2 teachers at each school. The topics of interviews conducted with teachers were about learning methods, learning models, and learning outcomes. Based on the results of interviews regarding methods, it is known that the methods used by teachers in the teaching and learning process are lecture, discussion, and question and answer methods. The use

of these methods still makes learning centered on the teacher. This causes a lack of exploration of the material by students so that there are several concepts that are not understood because they do not construct knowledge about the material independently.

The results regarding the learning models used in the learning process are as follows: teachers usually use inquiry-based learning models and problem-based learning models. The problems obtained from the use of these models according to teachers are because not all syntax in the model can be done because of the difficulty of delivery on certain materials. This affects students'

understanding of concepts because students are not directly involved in discovering a concept in the learning material.

The results of the study conducted on students were by providing diagnostic tests. Diagnostic tests were given to 216 students represented by 3 SMANs, namely SMAN 4, SMAN 9, and SMAN 11. The diagnostic tests were given on kinematics and dynamics materials. The results of the diagnostic tests conducted in 3 schools at SMAN Kota Padang can be seen in table 4.

Table 4. Diagnostic Test Results

School	Kinematics (%)				Dynamics (%)			
	UC	UCNS	M	DKC	UC	UCNS	M	DKC
SMAN 4 Padang	31.06	4,25	12.55	51.91	29.36	4.25	28.10	38.30
SMAN 9 Padang	35.56	5	17.22	41.11	35.56	5	17.22	41.11
SMAN 11 Padang	40	0	15.45	42.73	27.27	0	41.82	30.91

Table 4 shows the results of the diagnostic tests conducted at SMAN 4, SMAN 9, and SMAN 11. The interpretation of the scores for the kinematics material from each school can be seen in Figure 1.

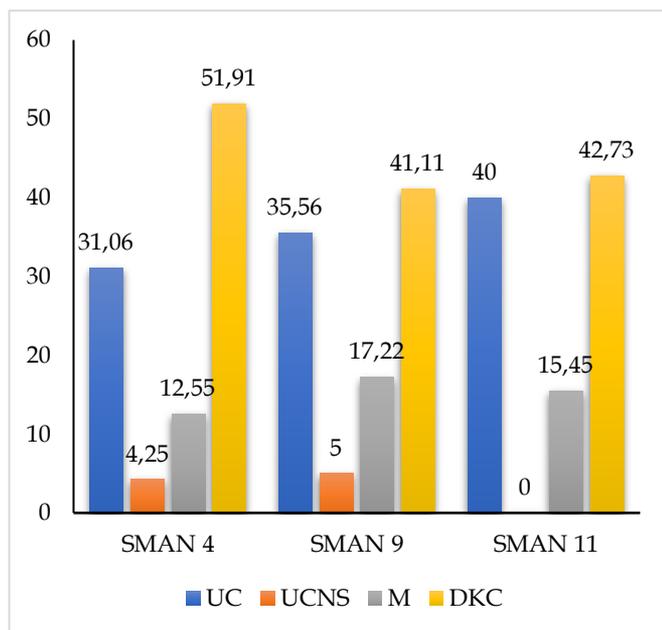


Figure 1. Diagnostic test scores of kinematics material

The results of the diagnostic test on kinematics material, as illustrated in Figure 1, reveal varying levels of conceptual understanding across three schools: SMAN 4, SMAN 9, and SMAN 11. The categories measured include Understanding the Concept (UC), Understanding the Concept but Unsure (UCNS), Misconception (M), and Not Knowing the Concept (DKC). SMAN 11 recorded the highest proportion of students in the UC category (40%), indicating a relatively

strong conceptual understanding among its students. This was followed by SMAN 9 (35.56%) and SMAN 4 (31.06%). These findings suggest that while some students in all schools are able to perform scientifically correct conceptual reasoning, the depth and distribution of understanding remain uneven.

In contrast, the UCNS category, which reflects partial understanding that is not yet aligned with scientific standards, showed minimal representation. SMAN 4 and SMAN 9 recorded low percentages, at 4.25% and 5% respectively, while SMAN 11 had no students in this category. This absence in SMAN 11 may indicate a binary distribution in which students either fully understand the concept or do not understand it at all, rather than having a partially formed but inaccurate idea.

A more concerning pattern emerges from the data on misconceptions (M). SMAN 9 showed the highest level of misconceptions (17.22%), followed by SMAN 11 (15.45%) and SMAN 4 (12.55%). This pattern suggests that a significant number of students not only lack understanding but also actively hold incorrect conceptual frameworks. Misconceptions are highly persistent and problematic in physics learning, as they can interfere with the acquisition of scientifically accurate knowledge if not explicitly addressed.

The DKC category, indicating a complete lack of understanding, dominated in all schools. SMAN 4 recorded the highest percentage in this category (51.91%), followed by SMAN 11 (42.73%) and SMAN 9 (41.11%). These figures indicate substantial gaps in basic understanding of kinematics, underscoring the need for teaching strategies that prioritize conceptual clarity and explicitly address gaps and misconceptions.

Kinematics material is often a conceptual challenge for students because it requires an understanding of mathematical and visual representations, such as graphs and vectors (Tatira, 2024). Common misconceptions include the assumption that acceleration only occurs when speed increases, or that a stationary object does not experience a force, when in reality acceleration can be negative and force can still act on a stationary object (Maryam, 2020). These conceptual errors usually stem from everyday experiences that are not always in line with the principles of physics, as well as from learning patterns that emphasize memorization rather than concept exploration. In addition, students' low ability to translate between representations - such as from verbal narratives to graphs, or from graphs to mathematical formulas - also contributes to the weak understanding of kinematics concepts (Firmansyah & Suhandi, 2021). For example, students often draw velocity-time graphs that do not match the description of motion, due to a lack of understanding of the relationship between the slope of the graph and acceleration or between the area of the graph and displacement. The high percentage of students in the Don't Know the Concept (DKC) and Misconception (M) categories emphasizes the need for effective learning interventions to support conceptual change. In this context, the cognitive conflict model is an important strategy to create dissonance between students' initial erroneous understanding and correct scientific information, thereby triggering a more scientific restructuring of concepts. When this model is integrated with a STEM-based approach, students are not only faced with conceptual contradictions theoretically, but also in a practical context through direct. For example, the use of Tracker software or motion sensors allows students to directly observe changes in speed over time and relate them to the graphs they have learned theoretically. The STEM-integrated cognitive conflict learning model encourages students to reconstruct their understanding through real experiences, problem solving, and the application of engineering principles, rather than simply memorizing material. This approach not only improves the understanding of kinematics concepts, but also develops systematic thinking skills, data analysis skills, and deeper scientific reflection – all of which are important competencies for fostering 21st-century scientific literacy (Bakri et al., 2020). With consistent implementation, it is expected that the level of misconceptions and conceptual ignorance will decrease, while students' scientific understanding will increase significantly.

Next, the interpretation of values for the dynamics material from each school can be seen in Figure 2.

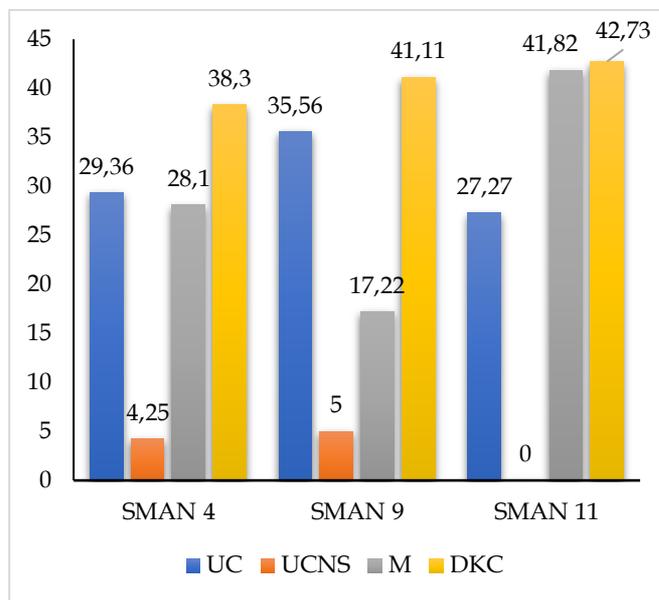


Figure 2. Diagnostic test scores of dynamics material

Based on the “Dynamics Material Diagnostic Test Scores” diagram, it can be seen that the dominance of the Don't Know the Concept (DKC) category indicates a fundamental problem in the mastery of dynamics concepts by students in the three schools. SMAN 11 occupies the highest position in the DKC category with a percentage of 42.73%, followed by SMAN 9 at 41.11%, and SMAN 4 at 38.3%. This indicates that most students do not understand the basic concepts of dynamics comprehensively.

Meanwhile, the percentage of Understanding the Concept (UC) did not reach the maximum of 40% in all schools, with the highest score at SMAN 9 at 35.56%, followed by SMAN 4 at 29.36%, and the lowest score at SMAN 11 at 27.27%. The low UC achievement indicates that most students still face difficulties in internalizing the basic principles of dynamics, such as Newton's laws, force and acceleration, and the interaction between mass and motion.

The Misconception (M) category also showed quite significant numbers, especially in SMAN 11 with the highest percentage of 41.82%. This shows that students not only do not understand the concept, but also have a wrong understanding. This kind of misconception, such as the assumption that force is always needed to maintain motion, needs to be identified and reduced through appropriate pedagogical interventions. The Understanding the Concept but Not Sure (UCNS) category showed very low results in all schools, even zero percent in SMAN 11. This can be interpreted that students are less confident in the understanding they have, or tend to choose answers randomly because they do not understand the concept as a whole.

Dynamics material in physics, which discusses the relationship between force and motion, is often a source

of misconceptions for students (Lubis & Bunawan, 2024). One common misconception is the assumption that force is always needed to keep an object moving at a constant speed, whereas according to Newton's first law, an object will continue to move in a straight line at a constant speed without external force if there is no force acting on it. In addition, students often misunderstand that a greater force always produces a greater acceleration, without considering the mass of the object which also affects acceleration according to Newton's second law (Ahlamy et al., 2022). This misconception can be caused by students' daily experiences that are not always in line with the principles of physics (Guerra-Reyes et al., 2024), as well as learning approaches that do not emphasize conceptual understanding. For example, in everyday life, to keep an object moving, it is often necessary to push it continuously due to friction, so students generalize that force is always needed to maintain motion. Students tend to understand motion based on everyday experiences that are not always in accordance with Newton's laws (Aini et al., 2023; Isra & Mufit, 2023). For example, students often assume that an object will only move if there is a force acting continuously on it, which is contrary to Newton's first law. In addition, in Newton's second law, students often fail to understand that acceleration depends not only on force but also on the mass of the object.

The application of a cognitive conflict-based learning model integrated with the STEM approach is a potential strategy in remediating misconceptions and building meaningful conceptual understanding. This model works by eliciting conflicts between students' prior knowledge and scientific reality presented through STEM project-based experiments or simulations, which can stimulate cognitive restructuring.

In the context of dynamics material, STEM integration allows students to construct their understanding through engineering processes and empirical observations. For example, in a STEM project, students can be asked to design a simple car system using an inclined plane or motion sensor to analyze the relationship between mass, force, and acceleration. With this approach, students not only understand the concept theoretically but also through direct experience involving scientific skills and critical thinking.

The implementation of this type of learning has been shown to be effective in improving conceptual understanding and reducing the level of misconceptions. A study by Fitriani et al. (2023) stated that the STEM approach combined with cognitive conflict strategies was able to significantly improve students' learning outcomes and conceptual understanding.

Conclusion

This study concludes that students' conceptual understanding of kinematics and dynamics material is still relatively low, with an average percentage of understanding of less than 50% and a high level of misconceptions, especially in Newton's laws and parabolic motion. The teacher-centered learning process causes students to be less active in building their own conceptual understanding, making it difficult to relate physics theory to its application in real life. A cognitive conflict-based learning model integrated with the STEM approach has great potential to improve this condition. This integration encourages students to reflect on their thinking through cognitive conflict experiences and real practices, creating more contextual, active, and meaningful learning. With consistent application, this model is expected to reduce the level of misconceptions and conceptual ignorance, while significantly increasing students' conceptual understanding.

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Author Contributions

P. N conceptualized the research idea, designed of methodology, management and coordination responsibility, analyzed data, conducted a research and investigation process; F. M dan F. N conducted literature review and provided critical feedback on the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest

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