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Diagnosing Junior High School Students' Misconceptions and Confidence on Force and Motion Using the Certainty of Response Index (CRI) and Written Reasoning Analysis

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ABSTRACT

Misconceptions in force and motion are persistent in junior high school and often remain hidden when assessment focuses only on correctness. Integrating students' confidence with their answers may improve diagnosis and inform instruction while also revealing critical thinking quality in written justifications. This descriptive study involved 50 eighth-grade students (SMP Evans Indonesia). Students completed 10 reasoned multiple-choice diagnostic items on force and motion (e.g., velocity–time graphs, force–acceleration relation, Newton's First Law), each accompanied by a Certainty of Response Index (CRI, 0–5). A cutoff of CRI ≥ 2.5 distinguished high vs low confidence. Written justifications were analyzed using Facione's critical thinking indicators (interpretation, inference, explanation, evaluation). Five students representing different conceptual profiles were selected for in-depth reasoning analysis. Misconceptions were most frequent in velocity–time graph interpretation and other abstract representations (about four in ten students showed confident, incorrect answers), while more concrete ideas (e.g., balanced forces) showed relatively higher understanding. Students classified as having misconceptions reported a higher mean CRI (~3.15) than students who answered correctly but were uncertain (~2.85), indicating a strong tendency towards false confidence. In the qualitative subsample, justification analysis revealed that interpretation (80%) and explanation (60%) were more common than inference (40%), while evaluation (0%) was absent. CRI-based diagnostics reveal deeply held misconceptions and limited higher-order reasoning. Instruction should explicitly target conceptual change and scaffold inference and evaluative thinking through simulations, graph-focused tasks, and structured argumentation.

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1. INTRODUCTION

Education at the junior high school (SMP) level plays a critical role in building a strong foundation of scientific knowledge, including physics. Students begin to engage more deeply with abstract scientific principles and processes at this stage, making it a crucial period for developing meaningful conceptual understanding. One of the main goals of physics learning is to help students master core concepts, principles, and scientific reasoning and develop critical thinking skills, problem-solving ability, and the capacity to apply scientific ideas in real-life contexts. However, a significant obstacle in achieving these objectives is the presence of misconceptions—inconceptual understanding that deviates from accepted scientific concepts. Misconceptions are persistent and resistant to change because they often align with students' everyday experiences and intuitive reasoning. If left unaddressed, these misconceptions can persist and hinder students' ability to understand more advanced topics or apply physics principles accurately in daily life or future academic learning.

From the perspective of constructivist learning theory, misconceptions arise naturally as students attempt to make sense of the world using their existing knowledge and experiences (Halid, 2024). In this framework, students are not "blank slates" but come to the classroom with prior conceptions that may or may not align with scientific views. These initial ideas, shaped by informal experiences, media exposure, and incomplete or inaccurate instruction, can become deeply rooted mental models. For example, many students believe heavier objects fall faster than lighter ones, despite the scientific principle that all objects fall at the same rate in the absence of air resistance. These beliefs often remain unless effectively challenged through targeted and interactive instructional methods. Physics, particularly topics involving motion and force, is one of the most common subjects in which students develop misconceptions. Concepts such as acceleration, net force, Newton's laws, and graphical motion interpretation are cognitively demanding and often conflict with intuitive thinking. According to a meta-analysis conducted by Kaltakci-Gurel, Eryilmaz, and McDermott (2020), misconceptions in mechanics, especially motion, are among the most prevalent globally among secondary school students. Similar trends are found in Indonesia, where Suparno (2013) and Linawati (2018) documented widespread student difficulty in interpreting velocity-time graphs, understanding the nature of force interactions, and distinguishing between motion types.

Duit and Treagust (2022) emphasize that conceptual change remains one of the central challenges in science education. They highlight the difficulty of helping students replace incorrect prior conceptions with scientifically accurate ones, especially when those misconceptions are held confidently. Teachers often face challenges identifying such misconceptions, particularly when assessments only evaluate surface-level recall. Thus, there is an urgent need for diagnostic tools that evaluate the correctness of students' responses and assess their confidence in those responses, providing insight into how deeply their understanding is rooted. One diagnostic tool that meets this need is the Certainty of Response Index (CRI). CRI allows for the identification of misconceptions not only based on incorrect answers but also by assessing how confident students are in their responses. For example, a student who answers incorrectly with high confidence will likely hold a strong misconception. Conversely, a student who answers correctly but with low confidence may indicate an unstable understanding that requires further reinforcement. Therefore, CRI serves as an evaluation instrument and a powerful diagnostic tool that provides deeper insights into student thinking, enabling educators to design more targeted instructional interventions (Hasan, Bagayoko, & Kelley, 1999).

Although CRI has been used extensively in higher education and research contexts, it remains underutilized in classroom-based studies at the junior high school level in Indonesia. Its potential for diagnosing misconceptions earlier in physics learning is significant, especially considering how foundational concepts like straight motion and force form the basis for more complex topics later in the physics curriculum. Studies such as those by Fia, Sugiyanto, and Yulian (2016) have shown that nearly 50% of students exhibit misconceptions related to motion, with only around 12% demonstrating accurate conceptual understanding. Furthermore, Maharta (2018) found that many students memorize physics formulas without internalizing their conceptual significance.

Given these challenges and opportunities, this study aims to explore eighth-grade students' misconceptions about straight motion using a CRI-based diagnostic test. Additionally, the study examines how students' confidence levels relate to their conceptual understanding, offering insight into the depth and nature of their reasoning. Beyond identifying misconceptions, the research also investigates students' critical thinking abilities by analyzing the justifications they provide for their answers. Critical thinking refers to the ability to interpret information, construct logical explanations, and evaluate one's understanding skills essential for scientific literacy (Facione, 1990). Students' written explanations are analyzed using key indicators of critical thinking, such as interpretation, inference, evaluation, and explanation. By implementing CRI in a classroom setting and combining it with an analysis of reasoning quality, this research contributes to the academic literature on physics education. It offers practical insights for improving diagnostic and instructional strategies. The findings are expected to inform curriculum planning, teacher training, and the development of more effective approaches to address conceptual misconceptions and reasoning skills in junior high school physics learning. Notably, while this study aims to identify students' misconceptions, it also seeks to highlight areas of conceptual strength and scientifically accurate reasoning, thereby providing a more balanced and comprehensive view of students' understanding.

2. METHODS

2.1 Research Instruments

This study employs a descriptive qualitative research design to explore students' misconceptions regarding straight motion in physics. The descriptive qualitative approach is considered suitable for gaining an in-depth understanding of the nature and causes of misconceptions through students' written reasoning and confidence levels. The participants in this study were 50 eighth-grade students from SMP Evans Indonesia, specifically from classes 8A and 8 B. Participants were selected using purposive sampling, focusing on students who had completed learning materials on straight motion. The school was selected based on accessibility and willingness to participate in the study. Before data collection, informed consent was obtained from students' parents or legal guardians. Students were told their participation was voluntary, and all ethical considerations, such as anonymity and confidentiality, were strictly maintained throughout the research.

The main instrument used was a diagnostic test in the form of reasoned multiple-choice questions integrated with the Certainty of Response Index (CRI). Each question required students to choose one answer, justify their reasoning, and indicate their confidence level on a scale from 0 (not sure) to 5 (very sure). The test consisted of 10 questions adapted from the diagnostic test on straight motion developed by Rakhmawati (2021). To ensure content validity, the test items were developed based on common misconceptions found in previous studies (e.g., Suparno, 2013; Maharta, 2018) and were reviewed by two physics education experts. A pilot test was conducted with 15 students from another school to evaluate item clarity and scale consistency. Revisions were made to improve the instrument quality based on their feedback.

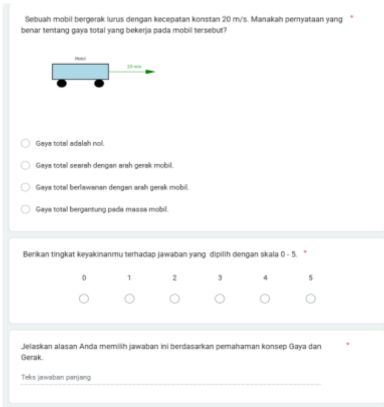

Figure 1. Example Of Diagnostic Test

An example of a diagnostic test item is presented in the Figure 1. A complete list of the ten diagnostic questions is also provided. The combination of multiple-choice format, reasoning, and CRI enabled the identification of scientifically correct conceptions, misconceptions, and guesses.

2.2 *Data Analysis Procedure*

The student responses were analyzed based on a classification scheme that combined the accuracy of their answers, the quality of their reasoning, and their Certainty of Response Index (CRI) values. A CRI cut-off score of ≥ 2.5 was used to distinguish between low and high confidence, following the method proposed by Hasan et al. (1999), who developed this threshold in their seminal study to identify confident misconceptions. This value has since been widely adopted in similar diagnostic research in science education. This method follows the conceptual analysis framework adapted from Hakim (2012), as shown in Table 1.

Table 1. Concept Understanding Criteria

Answer	**Reason**	**CRI Value**	**Description**
Correct	Correct	> 2.5	Concept Understanding
Correct	Correct	< 2.5	Understand the concept but not sure
Correct	Wrong	> 2.5	Misconceptions
Correct	Wrong	< 2.5	Don't know the concept
Wrong	Correct	> 2.5	Misconceptions
Wrong	Correct	< 2.5	Don't Know the Concept
Wrong	Wrong	> 2.5	Misconceptions
Wrong	Wrong	< 2.5	Don't Know the Concept

[1]Hakim (2012)

To further interpret the overall performance, students' conceptual understanding was categorized into five levels based on the percentage of correctly understood concepts. These classifications follow Labur (2008), as shown in Table 2.

Table.2. Categories of Student Concept Understanding

Category of Student Concept Understanding	Category Presentation of Concept Understanding (%)
Very Low	0.00 - 19.99
Low	20.00 - 39.99
Medium	40.00 - 59.99
High	60.00 - 79.99
Very High	80.00 - 100.00

[1]Hakim (2012)

This analytical framework enabled a deeper diagnosis of students' conceptual understanding and provided insight into the prevalence and depth of misconceptions across various straight motion concepts. In addition to identifying conceptual understanding and misconceptions, this study also aimed to evaluate students' reasoning skills as indicators of critical thinking. To achieve this, an analytical framework was adapted from Facione (1990), who defines critical thinking as purposeful, self-regulatory judgment involving core cognitive skills such as interpretation, inference, explanation, and evaluation. These indicators were used to analyze the quality of students' written justifications. A summary of these indicators and their application examples is presented in Table 3.

Table 3. Critical Thinking Indicators Adapted from Facione (1990)

Indicator	Description	Example of Application in Student Reasoning
Interpretation	Interpreting data or graphical information appropriately	"The flat line means constant speed, so it's uniform motion."
Inference	Drawing logical conclusions from evidence or known facts	"Because acceleration is zero, the object must be moving at a constant velocity."
Explanation	Providing scientific reasoning to support a claim	"It moves uniformly because the net force is zero, based on Newton's First Law."
Evaluation	Critically judging the accuracy or plausibility of an argument or claim	"Even though the graph goes up, it doesn't mean constant speed — that shows increasing speed."

Based on CRI classifications, five students were purposively selected from a pool of 50 to represent a range of conceptual profiles. Each profile was determined by combining the accuracy of answers with the students' CRI scores. Following Hasan et al. (1999), a CRI score ≥ 2.5 indicated high confidence. These students represented categories such as confident misconception (incorrect with high CRI), uncertainty (incorrect with low CRI), correct but uncertain, high understanding, and a mixed profile. Their written justifications were later analyzed qualitatively using the critical thinking indicators shown in Table 3.

3. FINDINGS AND DISCUSSION

Before analyzing the patterns of students' misconceptions, it is essential to explain the diagnostic approach used in this study. The Certainty of Response Index (CRI) is an analytical method that combines students' response accuracy with their confidence levels to identify the quality of their conceptual understanding (Hasan, Bagayoko, & Kelley, 1999). A correct response with low confidence may indicate guessing, while an incorrect response with high confidence reveals a misconception. This dual-dimensional analysis provides more nuanced insight into students' mental models than accuracy alone (Treagust, 2006; Odom & Barrow, 2007). Using CRI enhances the identification of persistent misconceptions, which are often based on intuitive reasoning that conflicts with formal scientific concepts (Vosniadou, 1994; McDermott, 2001).

3.1 Misconception Patterns by Concept

Based on the CRI diagnostic test results, students' understanding of straight motion concepts varies significantly across items. Table 1 summarizes the percentages of students categorized under each conceptual understanding level (conceptual understanding, misconceptions, not sure, and do not know) for each concept tested.

Table 4. Students' Conceptual Understanding by Item

No	Concept	Understood n(%)	Misconception n(%)	Not Sure n(%)	Do Not Know n(%)
1	Balanced Forces	17 (34%)	9 (18%)	11 (22%)	13 (26%)
2	Velocity–Time Graph	10 (20%)	21 (42%)	9 (18%)	10 (20%)
3	Force on Braking Car	12 (24%)	19 (38%)	9 (18%)	10 (20%)
4	Motion Without Force	13 (26%)	19 (38%)	9 (18%)	9 (18%)
5	Motion with Constant Speed	14 (28%)	18 (36%)	11 (22%)	8 (16%)
6	Free Fall	16 (32%)	15 (30%)	9 (18%)	10 (20%)
7	Instantaneous Speed	15 (30%)	14 (28%)	10 (20%)	11 (22%)
8	Graphical Interpretation of Acceleration	11 (22%)	18 (36%)	10 (20%)	11 (22%)
9	Deceleration and Direction	13 (26%)	17 (34%)	11 (22%)	9 (18%)
10	Newton's First Law	15 (30%)	16 (32%)	10 (20%)	9 (18%)

Table 4 presents students' conceptual profiles for each diagnostic item based on the CRI classification. Across all ten items (500 responses), the largest proportion of responses fell into the misconception category (165 responses; 33.0%), followed by understood (136; 27.2%). The remaining responses were distributed across not sure (99; 19.8%) and do not know (100; 20.0%), indicating considerable uncertainty and gaps in conceptual stability.

At the item level, the prevalence of misconceptions varied across concepts. The highest proportion of misconceptions occurred in Item 2 (Velocity–Time Graph), where 21 out of 50 students (42%) demonstrated confident incorrect understanding. High misconception rates also appeared in Item 3 (Force on a Braking Car) and Item 4 (Motion Without Force), each with 19 students (38%), as well as Item 5 (Motion with Constant Speed) and Item 8 (Graphical Interpretation of Acceleration), each with 18 students (36%). These items share a demand for reasoning about abstract representations (e.g., graphs) and the relationship between force and motion, which tends to elicit alternative conceptions.

In contrast, the highest proportions of conceptual understanding were observed for Item 1 (Balanced Forces) with 17 students (34%) and Item 6 (Free Fall) with 16 students (32%), followed by Item 7 (Instantaneous Speed) and Item 10 (Newton's First Law) with 15 students (30%) each. Despite these relatively higher values, the "not sure" and "do not know" categories remained substantial across nearly all items (typically around 18–26%), suggesting that many students either lacked confidence in correct reasoning or did not yet form stable conceptual models.

3.2. Confidence Levels and CRI Analysis

The Confidence Rating Index (CRI) analysis provides insight into the students' self-perceived understanding. Based on the data, there was a significant difference in the average CRI among the comprehension categories: misconceptions, conceptually aware, conceptually aware but not confident, and conceptually unaware. The analysis showed that students with misconceptions had a higher average CRI than those who conceptual understanding but expressed uncertainty. This indicates that students with misconceptions often possess false confidence in their incorrect answers. In contrast, students who answered correctly but with lower confidence may require further reinforcement to strengthen their conceptual grasp.

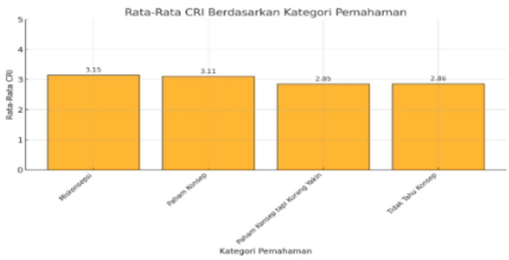

Figure 2. Average CRI by Category of Physics Concept Understanding

The average CRI score for students in the misconception category was 3.15, suggesting strong confidence in incorrect reasoning. This result reinforces the notion that misconceptions are not simply due to lack of knowledge but may stem from intuitive beliefs reinforced by prior experience or traditional instruction. On the other hand, the category "Understand the Concept but Less Confident" showed a lower CRI (2.85), which implies that while some students possess conceptual understanding, they may still hesitate to trust their reasoning. This could be improved through feedback-based learning environments and more conceptual practice.

3.3. Relationship between Misconceptions and Physics Teaching Challenges

The misconceptions among students in physics learning indicate significant challenges in the teaching process. Based on research results, students often have misconceptions about abstract physics concepts, such as the relationship between force and acceleration or the interpretation of velocity-time graphs. This can be attributed to the limitations of traditional teaching methods that focus on memorization and provide students with less visual or experimental exploration experience. The high level of misconceptions, as seen in question 5, indicates that students fail to understand the concepts correctly and have high confidence in their incorrect answers. This poses an additional challenge for teachers, namely, how to help students understand concepts correctly and develop reflection on their own thinking.

This gap often arises because physics instruction lacks emphasis on developing accurate mental models and linking concepts to everyday phenomena. Another challenge is overcoming misconceptions rooted in students' everyday intuitions. For example, students may believe that acceleration always follows the direction of motion, without understanding the underlying principle of net force and motion. In addition, the proportion of students who "understand the concept but are not sure" illustrates the need to build confidence alongside comprehension. Teachers are encouraged to foster a learning environment that promotes discussion, concept exploration, and formative feedback. In conclusion, addressing misconceptions in physics requires delivering accurate content, nurturing students' confidence, and encouraging reflective thinking. Innovations in instruction that integrate simulations, phenomenon-based learning, and adaptive feedback strategies are essential to support students' conceptual growth and reduce persistent misconceptions.

3.4. Critical Thinking Patterns Based on Student Reasoning

This study employed a diagnostic framework that connects three core components: conceptual understanding, certainty level (CRI), and critical thinking indicators to deepen the understanding of how students reason about straight motion. This framework enabled the researcher to trace the process from students' answer patterns to their reasoning quality. Figure 3 presents an overview of this analytical approach. This figure was developed in response to the need to visualize how conceptual understanding (identified through CRI) relates to students' reasoning patterns based on critical thinking indicators.

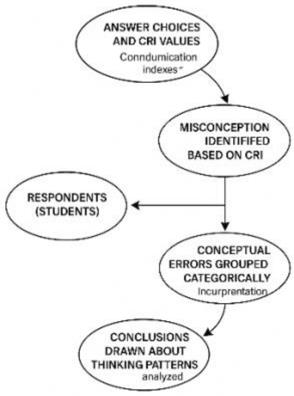

Figure 3. Analytical Framework Linking CRI Scores, Conceptual Profiles, and Critical Thinking Indicators

In this framework, misconceptions are not identified solely through incorrect answers but are linked to students' high confidence levels (CRI ≥ 2.5). This indicates that students are not merely guessing but are actively holding incorrect understandings they believe to be true. Thus, CRI bridges conceptual knowledge and reasoning quality: students confident in incorrect responses tend to exhibit distinct critical thinking patterns. After students were categorized into five conceptual profiles based on the combination of answer correctness and CRI scores, namely confident misconception, lack of knowledge, correct but uncertain, high conceptual understanding, and mixed profile, their written justifications were further analyzed using critical thinking indicators proposed by Facione (1990). The results showed that students with conceptual understanding tended to be weaker in evaluation and inference. In contrast, those with accurate conceptual understanding and high confidence exhibited more scientifically consistent reasoning patterns. In other words, misconceptions, CRI, and critical thinking indicators do not operate independently but are interrelated. CRI mediates the strength of conceptual errors, which is reflected in the quality of students' critical reasoning. This interaction forms the foundation for further analysis of students' scientific thinking patterns.

Five students were purposively selected to explore their reasoning in depth based on diverse conceptual profiles identified through their CRI scores and answer correctness. Table 4 presents the diagnostic profiles of these students.

Table 4. Conceptual Profiles of Selected Students Based on CRI Scores and Answer Correctness

Student Code	Analyzed Item(s)	Answer	CRI Score	Conceptual Profile
S1	Item 3	Incorrect	3.2	Confident Misconception
S2	Item 5	Incorrect	1.8	Uncertain (Lack of Knowledge)
S3	Item 7	Correct	1.6	Correct but Uncertain
S4	Item 2	Correct	3.5	High Conceptual Understanding
S5	Item 1: Correct, CRI 2.7Item 4: Incorrect, CRI 2.9Item 6: Correct, CRI 1.9	Mixed	–	Mixed Profile

The written justifications provided by these five students were then analyzed using critical thinking indicators adapted from Facione (1990): interpretation, inference, explanation, and evaluation. Each student's explanation was examined for the presence of these indicators, and the frequency of each indicator across the five participants was quantified. The results are summarized in Table 5.

Table 5 . Critical Thinking Patterns Based on Student Reasoning

Indicator	% of Students Demonstrating
Interpretation	80%
Inference	40%
Explanation	60%
Evaluation	0%

The most frequently observed critical thinking indicator among the five students was interpretation (80%), which primarily appeared when students described motion graphs or identified motion types. Explanation was evident in 60% of students' responses, particularly when they justified their answers by referring to physical concepts such as Newton's Laws. In contrast, inference was observed less frequently (40%), and evaluation was absent. This pattern indicates that although some students demonstrated the ability to interpret data and explain phenomena using scientific principles, they did not engage in reflective assessment of their reasoning processes.

These findings are consistent with international studies. Kaltakci-Gurel et al. (2017) found that misconceptions in interpreting motion graphs are widespread and resistant to change, a pattern that also emerged in this study. Potvin and Cyr (2017) emphasized that students' intuitive beliefs often hinder deeper scientific reasoning. In the foundational work by Hasan et al. (1999), the Certainty of Response Index (CRI) was introduced to identify firmly held misconceptions. The present study extends this approach by integrating CRI-based classifications with the analysis of critical thinking indicators (Facione, 1990), thereby mapping the relationship between students' confidence in their conceptual understanding and the quality of their scientific reasoning.

3.5. Limitations of the Study

This study acknowledges several limitations. First, the qualitative analysis involved a small purposive sample of five students, which, while appropriate for in-depth exploration, limits the generalizability of the findings to broader populations. Second, the research was conducted in a specific educational context, and its findings may not fully represent students from different schools or cultural settings. Third, the analysis relied solely on written justifications without triangulation through interviews or classroom observations, which may have restricted the depth of insight into students' reasoning processes. Finally, while a structured framework was used for critical thinking analysis, researcher interpretation of open responses could introduce potential bias despite efforts to ensure consistency.

The absence of evaluation suggests a lack of metacognitive awareness and critical self-assessment, essential for advanced scientific reasoning. This finding is consistent with previous studies indicating that such skills are typically underdeveloped in early adolescence and often require explicit instruction and modeling to emerge (Kuhn, 2000; Facione, 1990). From a constructivist perspective, learning is most effective when students actively construct meaning through guided inquiry and social interaction (Vygotsky, 1978). The frequent appearance of interpretation and explanation in this study implies that students can build understanding when provided with meaningful reasoning tasks. However, the lack of evaluative thinking reveals that students may remain at a descriptive level without intentional scaffolding. These findings emphasize the need for instructional strategies supporting higher-order thinking development. Approaches such as open-ended questioning, peer feedback, counterexample exploration, and structured argumentation (Ennis, 1996) can facilitate metacognitive engagement and promote critical evaluation. In line with constructivist principles, such strategies help students move beyond surface understanding toward deeper reasoning and reflective judgment.

4. CONCLUSION

This study found that misconceptions are a major barrier to eighth-grade students' understanding of force and motion, particularly in interpreting velocity–time graphs and linking force to acceleration, and that these incorrect ideas are often held with high confidence, indicating deeply rooted alternative conceptions that may not be addressed by traditional instruction; the Certainty of Response Index (CRI) was effective for distinguishing confident misconceptions from uncertainty, while analysis of written justifications showed students mostly demonstrated interpretation and basic explanation but rarely engaged in higher-order critical thinking such as inference and self-evaluation. A key limitation is that the research was conducted in a single school context and the in-depth critical thinking analysis relied on a small purposive subsample of students and written responses only, limiting generalizability and depth of insight into students' reasoning processes. Future research should involve larger, more diverse populations and use triangulation methods (e.g., interviews, classroom observations, or think-aloud protocols) to better explain why confident misconceptions persist and to test instructional interventions designed to promote conceptual change alongside stronger inferential and evaluative reasoning.

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Conflicts of Interest: The authors declare no conflict of interest.

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