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The characteristics of real and pseudo-true thinking in STEM students' analytical thinking process in solving set problems

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Abstract
It is essential to analyze students' cognitive development, particularly in mathematics, to determine their ability to solve problems effectively. This research focuses on analytical thinking as a critical component of students' problem-solving processes in mathematics. The subjects of this study were two students from a school in Bandung who are part of a STEM program, which incorporates additional learning approaches in science, technology, engineering, and mathematics. Through this approach, researchers aim to understand the students' analytical thinking processes and characteristics in solving given problems using qualitative methods. The instruments utilized in this study were tests and interview guidelines. The findings revealed that each student exhibited two distinct analytical thinking characteristics. The "real true thinking" character is where students can provide justification for their correct problem-solving results and navigate through the entire analytical thinking process. In contrast, the pseudo-true thinking character is unable to justify correct problem-solving and fails to complete the analytical thinking process, particularly at the differentiation stage.

Keywords: Analytical, STEM, Thinking character

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Introduction

Children's cognitive development is a gradual process involving changes in their thinking, understanding, and problem-solving abilities. Jean Piaget identified four stages of cognitive development, which describe the evolution of students' cognitive processes over time. The sensorimotor stage (birth to 2 years) is characterized by learning through sensory experiences and physical interactions with the environment. In the preoperational stage (2 to 7 years), children develop symbolic thinking, imagination, and language, but they struggle with logical reasoning and understanding others' perspectives. The concrete operational stage (7 to 11 years) marks the emergence of logical thinking, mastery of conservation, and the ability to solve problems using concrete objects or scenarios, although abstract thinking remains limited. Finally, the formal operational stage (12 years and up) is defined by the ability to think abstractly, use deductive reasoning, and systematically solve problems, enabling students to tackle complex and hypothetical scenarios. Each stage reflects a distinct way of interacting with and understanding the world, thereby shaping how students learn and process information (Rabindran & Madanagopal, 2020; Sidik, 2020).

Student cognitive development is a process involving changes and growth in their ability to think, understand, and solve problems from childhood to adolescence. This encompasses how students process information, comprehend concepts, and develop more sophisticated thinking skills over time. Analyzing students' cognitive development is crucial in mathematics education to understand their problem-solving abilities. Teachers can leverage this information to design instruction that aligns with students' developmental levels. Evaluating problem-solving capabilities—such as problem comprehension, strategies employed, thought processes, and knowledge transfer—enables teachers to provide appropriate support and implement effective teaching methods. By understanding and adapting instruction to students' cognitive development, teachers can assist students in reaching their maximum potential in mathematics (Carifio, 2015; Shuell, 1986). Cognitive development, especially in problem-solving, reveals four possible thinking characters among students. The first is the "real true thinking" character, where a student not only answers correctly but also provides accurate justification. For example, when asked to calculate the area of a square with a side length of 5 cm, the student answers 25 cm^2 and justifies it by explaining that the area is calculated using the formula $s \times s$, thus $5 \times 5 = 25$. The second is the pseudo-true thinking character, where a student provides the correct answer but cannot justify it. For instance, the student states the area is 25 cm^2 but explains, "I just remember the answer," without proper explanation. The third is the pseudo-false thinking character, where the student initially provides an incorrect answer but, after reflection, realizes the mistake, corrects the answer, and provides justification. For example, the student first says the area is 20 cm^2 but, upon reflection, corrects it to 25 cm^2 and explains the formula. Finally, the "real-false thinking" character describes a student who provides an incorrect answer and cannot justify or improve their response. For instance, they say the area is 15 cm^2 and are unable to explain or rectify their answer. These four characteristics highlight the diversity in students' approaches to problem-solving and represent the varied thinking characters students exhibit in problem-solving contexts (Subanji, 2011).

Analytical thinking is a method for examining how students' cognitive development progresses. According to Anderson, analytical thinking is a cognitive process that involves decomposing information into smaller components, identifying relationships between these components, and evaluating evidence to understand concepts or solve problems (Anderson et al., 2001). In mathematics education, this ability is crucial for helping students achieve a deeper understanding and effectively apply their knowledge (Karenina et al., 2019; Qolfathiriyus et al., 2019). Within the analytical thinking framework proposed by Anderson and Krathwohl, there are three primary stages essential for understanding and application in mathematics education: differentiating, organizing, and attributing (Maqruf et al., 2023; Wijaya et al., 2023; Anderson et al., 2001). In the first stage, differentiating, students must be able to identify and separate various elements, concepts, or information. For example, in solving algebra problems, students need to understand the differences between variables, constants, and coefficients, as well as the functions and relationships among them. The next stage is organizing, where students group differentiated elements into larger categories or arrange information logically. In a mathematical context, this could mean sequencing the steps of a solution correctly or organizing data into a table. Finally, at the stage of attributing, students evaluate and assign characteristics to the organized elements. This involves relating relevant mathematical methods or principles to the attributes of given data or situations, such as selecting the most effective solution method for a particular type of problem. By understanding and applying these three stages, students not only gain a deeper understanding of mathematical concepts but also develop critical thinking and more sophisticated problem-solving skills (Mahyastuti et al., 2021; Syavarizca & Sumaji, 2021; Waskita et al., 2019).

One of the more complex areas in mathematics is Algebra. Among the fundamental concepts in algebra that students need to master is set theory. Set theory at the junior high school level often presents challenges for students for several reasons. Students frequently struggle with understanding and using set notation, such as distinguishing between empty sets and sets with a single element. They also encounter difficulties in performing set operations such as union, intersection, and difference, as well as in drawing and interpreting Venn diagrams. Additionally, the concept of subsets can be particularly confusing, especially as the number of elements increases. To address these challenges, it is essential for teachers to provide ample practice opportunities, utilize visual tools, and clearly explain the underlying concepts (Lestari & Roesdiana, 2022; Loviasari & Mampouw, 2022; Dwidarti et al., 2021). Thus, the challenge presented by set theory warrants research into how students' thinking characteristics influence their ability to solve set-related problems.

In this research, the focus is on STEM students as the subjects of study. STEM students are individuals actively engaged in education and activities centered on Science, Technology, Engineering, and Mathematics (Henriksen, 2014; Roberts & Diana Cantu, 2012). STEM students often exhibit strong analytical and problem-solving skills, employing scientific methods and logic to comprehend and address complex challenges (Ruangsiri et al., 2022). With a profound interest in experimentation and research, STEM students frequently engage in projects that involve data collection and hypothesis testing, utilizing various tools and technologies for information analysis. They often learn through a project-based approach that integrates multiple disciplines, involving designing, building, and testing solutions or products. STEM education aims to prepare students to face the challenges and opportunities in an increasingly technology-driven world by enhancing critical and creative abilities, preparing them for promising careers in STEM fields, and encouraging lifelong learning. Thus, STEM students develop in an environment that prioritizes the cultivation of skills and knowledge in technology and innovation-oriented fields, enabling them to acquire advanced thinking skills (Cheng et al., 2022; Li & Schoenfeld, 2019; Uzzo et al., 2018). However, do all students with advanced thinking abilities possess strong analytical thinking skills in solving mathematics? Several studies related to analytical thinking have been conducted. One study indicates that this ability is influenced by students' cognitive styles, which support in-depth problem-solving (Qolfathiriyus et al., 2019). Art-in (2014) emphasized the importance of developing analytical thinking-based learning management, which not only enhances teachers' ability to design effective learning experiences but also improves student learning outcomes and satisfaction. Syavarizca & Sumaji (2021) connects analytical thinking with high-level thinking skills (HOTS), demonstrating that analytical thinking, according to the revised Bloom's Taxonomy, is an integral component of C-4 in the cognitive domain. Additionally, Ilma et al. (2017) found that students with visualizer and verbalizer cognitive styles were equally adept at analytical thinking, though they employed different approaches to problem-solving. Despite these findings, none of these studies have specifically examined the characteristics of students' analytical thinking, particularly from the perspective of pseudo-thinking. Based on previous theoretical studies, this research will explore the characteristics of real and pseudo-true thinking in the analytical thinking processes of STEM students when solving set-related problems.

Methods

This research employs a qualitative case study approach, presenting an analysis of students' thinking characteristics in solving set-related problems. In this study, researchers act as planners, implementers, data collectors, data interpreters, and reporters of the research results. The activities conducted by the researchers include collecting direct observation data, conducting interviews, recording student activities during group problem-solving sessions, gathering data in the form of test results, and drawing conclusions to compile the research report.

Subject

The subjects of this research were two students from a school in Bandung, Indonesia, who received additional STEM learning approaches. The decision to select only two students is based on the study's aim to deeply analyze students who demonstrate correct problem-solving strategies. By focusing on students who provide accurate solutions, the research can explore their cognitive processes, justifications, and understanding within the context of STEM learning. This qualitative approach allows for a detailed examination of their thinking characteristics and enables the identification of specific factors contributing to successful analytical thinking. Therefore, in this qualitative research, purposive sampling was employed, selecting the best individuals or locations that can help us understand the phenomenon (Creswell, 2014). The subjects chosen were two students selected randomly, who were able to answer the set questions correctly. These two samples were able to communicate effectively, were willing to participate, and were representative of the group (STEM students who successfully answered set questions). Based on the subject selection results, two subjects were found who answered the set questions correctly. These subjects were chosen randomly and exhibited two distinct thinking characteristics: real true thinking and pseudo-true thinking, as illustrated in Table 1.

Table 1. Results of Research Subject Categories

Name Initials	Code	Thinking Character Category
KAL	SBS	Really True
RZBW	SPB	Pseudo True

SBS exhibits a real true thinking character, excelling in solving group problems. SPB, on the other hand, demonstrates a pseudo-true thinking character in solving set problems.

Research Instruments

The instruments used in this research included a set problem test sheet and an interview guide. The set problem test was conducted to provide an overview of students' analytical thinking at each stage of the problem-solving process. Meanwhile, the interview guide served as a tool for conducting interviews to gain deeper insights into the students' thinking processes. The following are the set problem test instruments utilized in the research (see Figure 1).

> Di suatu kelas, terdiri dari 32 siswa. Diketahui 17 siswa menyukai matematika, 17 siswa menyukai IPA, sementara 5 siswa tidak menyukai matematika dan IPA. Dari informasi tersebut, lebih banyak manakah antara siswa yang tidak menyukai Matematika dan IPA atau siswa yang menyukai Matematika dan IPA? Berikan penjelasan dari jawaban anda!

Figure 1. Set Problem Test Instrument

Translation of set problem test instrument (Figure 1):

> In a class consisting of 32 students, it is known that 17 students like mathematics, 17 students like science, and 5 students do not like either mathematics or science. Based on this information, determine which is greater: the number of students who do not like mathematics and science, or the number of students who like mathematics and science? Provide a justification for your answer.

The set problem test instrument above was developed from questions related to subsets in the book Bright to Abstract Mathematics by (Morash, 1987). The test item was validated by expert validators to ensure its accuracy, relevance, and alignment with the research objectives. These expert validators were postgraduate mathematics lecturers at universities, holding a minimum educational qualification of a doctorate. The validation process involved a comprehensive review of the test instrument, focusing on question clarity, cognitive demand suitability, and alignment with STEM learning objectives. Additionally, the interview guide was reviewed to ensure that the questions effectively elicited meaningful responses related to students' problem-solving processes and thinking characteristics. Feedback from the validators was utilized to refine and improve the instrument, ensuring it was robust and capable of capturing the desired data for the study. Once refined, the validators declared the instrument fit for use.

Data Collection and Analysis Techniques

Data collection in this research comprises test result data, interview data, observation data, and audio recording results. The research data were obtained from tests conducted to solve group problems and interviews with the research subjects. To ensure the validity of the data, the interview process was documented by recording the interactions between the researcher and the subjects. The recorded interviews were then transcribed to minimize the risk of missing information. The analysis of the research data employed qualitative data analysis techniques, which consisted of six stages: preparing and organizing data, exploring and coding data, describing data, presenting and reporting findings, interpreting research findings, and validating the accuracy of the findings (Creswell, 2012).

Result

These results pertain to the outcomes of the problem-solving tasks and the subsequent interviews with the subjects, as detailed below:

Subject's Analytical Thinking Process with Real True Thinking Character

The results of the written test in solving set problems indicated that SBS completed all stages of analytical thinking comprehensively. SBS detailed the steps in determining solutions to problems with precise and accurate calculations, as illustrated in Figure 2 below:

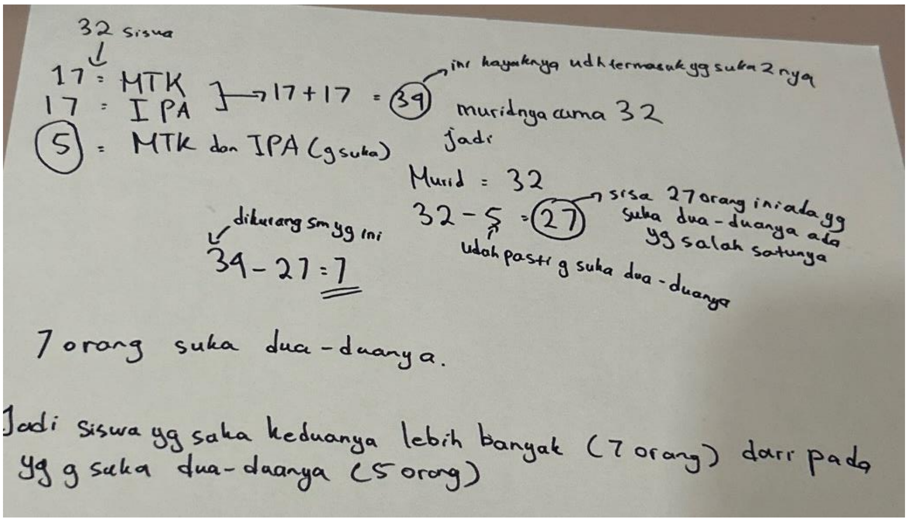

Figure 2. Results of working on SBS questions

Explanation and Translation:

> There are 17 students who like mathematics and 17 students who like science in a class of 32 students. Adding the numbers together results in 34 students; however, since there are only 32 students in the class, it indicates that 7 students like both subjects. This means that there are more students who like both subjects (7 students) compared to those who do not like either subject (5 students).

In Figure 2, it is observed that SBS conducted the differentiating stage by noting the essential known elements. Additionally, SBS was able to formulate ideas by summing the number of students who like mathematics and science, which exceeded the total number of students in the class, thereby confirming that some students like both subjects. Based on these ideas at the differentiating stage, SBS successfully determined the number of students who like both mathematics and science during the organizing stage by subtracting the number of students who like only mathematics and those who like only science from the total number of students in the class, after accounting for those who do not like either subject. Finally, SBS executed the attributing stage by concluding that the number of students who like both mathematics and science is greater than the number of students who do not like either subject.

Furthermore, the problem-solving results are supported by the interview findings, as illustrated in the following transcript.

P	:	*From the problems presented, what are the important parts? Can you tell?*
SBS	:	*From a class consisting of 32 students, it is known that 17 students like mathematics and 17 students like science, and 5 do not like mathematics and science*
P	:	*Then after that you were asked to look for what?*
SBS	:	*Looking for those who don't... uh, which ones like mathematics and science more or those who don't like math and science? That means looking for someone who likes both*
P	:	*Why do some people like both? I'm looking for those who like both. Why do you think there are people out there who like both?*
SBS	:	*Because there are still more than 17 students who like mathematics and 17 students who like science*
P	:	*So how?*
SBS	:	*Maybe someone likes both*

Based on the transcript above, SBS is able to provide appropriate justification in explaining the important parts necessary to solve the association problem, both in writing and verbally. SBS effectively identifies and distinguishes the critical elements of the problem, thereby engaging in the analytical thinking stage of differentiating. This differentiating behavior is demonstrated by SBS's comprehensive and accurate explanation of the essential aspects of the problem. SBS also posits that a significant number of students are likely to enjoy both mathematics and science.

P	:	*After that, how do you do it?*
SBS	:	*32 minus those who don't like mathematics and science*
P	:	*OK, after that?*
SBS	:	*Then the remaining 27 is to subtract the number of students who like mathematics only and science only, namely 34.*
P	:	*After that?*
SBS	:	*The result is 34-27 meaning 7 people*
P	:	*Okay. Meaning the conclusion?*
SBS	:	*There are more students who like both subjects than those who dislike both subjects*
P	:	*Are you sure about the answer?*
SBS	:	*Certainly*

Furthermore, based on the transcript above, SBS successfully completed the organizing stage by subtracting the number of students who liked only mathematics and the number of students who liked only science from the total number of students in the class, after accounting for those who did not like either subject. Finally, SBS executed the attributing stage by concluding that the number of students who liked both mathematics and science was greater than the number of students who did not like either subject. Therefore, it can be concluded that SBS performed all stages of the analytical thinking process comprehensively: differentiating, organizing, and attributing.

Analytical Thinking Process of Subjects with Pseudo Correct Thinking Character

The results of the written test in solving set problems indicated that SPB attempted all stages of analytical thinking but did not complete them thoroughly. SPB was unable to outline the steps in determining the solution to the problem, as shown in Figure 3.

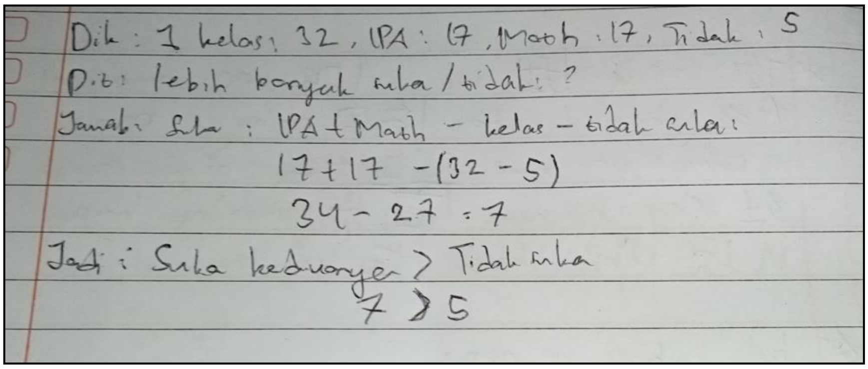

Figure 3. Results of working on SPB questions

Explanation and Translation:

> To determine whether there are more students who like or dislike both subjects, one must first subtract the number of students who like only science and mathematics from the total number of students in the class, which has already been reduced by 5. It is found that the number of students who like both subjects is greater than those who do not.

In Figure 3, it is observed that SPB undertook the differentiating stage by noting the critical known elements. However, SPB was unable to plan ideas by summing the number of students who like mathematics and science, which turned out to exceed the total number of students in the class. SPB only responded according to the given questions, indicating that some students must like both subjects.

During the differentiating stage, SBS successfully identified the number of students who liked both mathematics and science at the organizing stage by subtracting the number of students who liked only mathematics and those who liked only science from the total number of students in the class, after accounting for those who did not like either subject. Finally, SBS executed the attributing stage by concluding that the number of students who liked both mathematics and science was greater than the number of students who did not like either subject.

Furthermore, the problem-solving results are supported by the interview findings, as illustrated in the following transcript:

P : *From the problems presented, what are the important parts?*

		Can you tell?
SPB	:	*From a class consisting of 32 students, it is known that 17 students like mathematics and 17 students like science, and 5 do not like mathematics and science*
P	:	*Then after that you were asked to look for what?*
SPB	:	*Looking for someone who likes both because it's not yet known*
P	:	*Why do you think there are people out there who like both?*
SPB	:	*Yes, because as asked, there are definitely people who like both*
P	:	*So how?*
SPB	:	*Yes, we need to find those who like both to compare with those who don't like both*

Based on the transcript above, SPB has not been able to provide appropriate justification in describing the essential parts needed to solve the association problem. Consequently, SPB has been unable to explain the crucial elements of the problem, both in writing and in interviews. SPB has not identified and differentiated the important parts of the problem completely, thus failing to fully execute the differentiating stage. SPB's differentiating behavior is limited to rewriting the known part of the given question, without indicating the possibility of an important element that might emerge, such as identifying that many students might like both subjects by connecting other key aspects within the given question.

P	:	*After that, how do you do it?*
SPB	:	*Many students in the class, namely 32 minus, do not like mathematics and science*
P	:	*OK, after that?*
SPB	:	*Then the number of students who like only mathematics and only science is 34, subtracting the previous result from 27.*
P	:	*After that?*
SPB	:	*The result is 34-27 meaning 7 people*
P	:	*Okay. Meaning the conclusion?*
SPB	:	*There are more students who like both subjects than those who dislike both subjects*
P	:	*Are you sure about the answer?*
SPB	:	*Certainly*

Furthermore, based on the transcript above, SPB was able to execute the organizing stage by subtracting the number of students who liked only mathematics and those who liked only science from the total number of students in the class, after accounting for those who did not like either subject. Finally, SPB completed the attributing stage by concluding that the number of students who liked both mathematics and science was greater than the number of students who did not like either subject. Therefore, it can be concluded that while SPB did not fully engage in all stages of the analytical thinking process, they completed the organizing and attributing stages, but did not fully complete the differentiating stage.

Discussion

In analyzing the characteristics of analytical thinking among STEM students who successfully answered the questions, a relationship was found. Both subjects with real true thinking and pseudo-true thinking characters were equally able to complete the organizing and attributing stages. However, subjects with pseudo-true characters did not fully complete the differentiating stage.

SBS provided correct answers and justifications. The subject fully carried out the differentiating stage of analytical thinking. SBS accurately identified and connected the essential parts of the given problem, ensuring a thorough understanding and execution of the differentiating stage. Subsequently, SBS effectively organized and implemented a plan to solve the problem set. In the final stage of analytical thinking, attributing, SBS provided a meaningful solution and conclusion that addressed the problem set.

These findings align with previous studies, indicating that subjects with strong analytical thinking characteristics possess an accurate understanding. They are true critical thinkers. This study further reinforces the evidence that students with strong analytical thinking skills exhibit precise thinking characteristics in project-based learning environments, such as those involving STEM. This alignment demonstrates that the integration of STEM approaches not only enhances student engagement in authentic and interdisciplinary tasks but also supports the development of accurate and well-justified reasoning. By fostering analytical thinking within a structured STEM framework, students are more likely to demonstrate a deep understanding and provide logical justifications for their problem-solving processes, validating the role of STEM education in nurturing true critical thinking (Romli, 2016; Wibawa, 2016).

The second characteristic observed is a subject with a pseudo-true thinking character. SPB provided the correct answer but was unable to offer a justification. The subject did not fully engage in the differentiating analytical thinking stage. SPB did not adequately determine and confirm that some students liked both subjects by connecting the critical elements of the given problem. Consequently, SPB did not completely understand the important parts and did not fully execute the differentiating stage. Instead, SPB merely rewrote the known parts of the question.

In the organizing stage, SPB was able to plan and execute solutions to the group's problems. At the attributing stage, SPB provided the meaning of the solution and concluded with an answer to the given problem set. Ultimately, SPB did not complete the full analytical thinking process, despite providing correct answers, indicating an incomplete understanding. This aligns with previous research, which suggests that subjects with poor analytical thinking characteristics exhibit poor understanding and can be categorized as pseudo-true thinkers.

The findings of this study further reinforce the notion that students with weak analytical thinking skills tend to exhibit pseudo-true thinking characteristics, even in project-based learning environments like STEM. This indicates that while STEM learning fosters engagement with real-world problems and interdisciplinary tasks, students with underdeveloped analytical abilities may struggle to provide accurate justifications, relying instead on surface-level reasoning or rote memorization. These results underscore the importance of supporting the development of analytical thinking within STEM education to ensure that all students can progress beyond pseudo-true thinking and achieve deeper, more accurate understanding (Agustin et al., 2018; Vinner, 1997; Widiyastuti & Jazuli, 2019).

Conclusion

The conclusion of the study is that when STEM students solve set problems, there are two distinct characteristics of analytical thinking observed among students who answer the questions correctly. Among the research subjects, two types of analytical thinking were identified: real true thinking and pseudo-true thinking. Each student approaches set problems through stages of analytical thinking, but the completeness of these stages varies based on the individual's thinking characteristics.

The primary difference between these characteristics lies in the differentiating stage. STEM students with real true thinking are able to complete all stages of analytical thinking, while those with pseudo-true thinking do not fully complete the differentiating stage. Future studies could focus on developing and testing learning approaches that specifically support students with pseudo-true thinking characteristics. These approaches might include scaffolding strategies, targeted interventions, or adaptive teaching methods that emphasize critical components of analytical thinking, such as differentiation, organization, and attribution. Incorporating reflective practices, peer collaboration, and problem-solving tasks tailored to gradually enhance students' cognitive skills could also prove beneficial. Such research could provide valuable insights into effective instructional designs that help these students bridge the gap between superficial understanding and deep, justified reasoning in STEM learning environments.

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