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PSEUDO-UNDERSTANDING IN MATHEMATICS: THE ROLE OF HABITS OF MIND AND GENDER DIFFERENCES

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Abstract
This study explores the role of habits of mind and gender differences in shaping students' mathematical understanding, focusing on pseudo-understanding. Using a mixed-methods approach with a sequential explanatory design, the study involved 57 first-semester students of the Mathematics Education program at one of the public universities in Indonesia. Data were collected through mathematical concept comprehension tests, questionnaires on habits of mind, and semi-structured interviews. Three mathematics education experts validated the research instruments prior to their use. Quantitative data analysis was carried out descriptively to identify patterns of relationships among conceptual understanding, thought habits, and gender differences, while qualitative data were analyzed using a thematic approach. The results show that mind habits such as perseverance, cognitive flexibility, and reflection are essential in reducing pseudo-comprehension. Gender differences affect how students interact with mathematics, where stereotypes can hinder the development of strong habits of mind. This research highlights the importance of a pedagogical approach that emphasizes conceptual understanding and creates an inclusive classroom environment to diminish the risks of pseudo-understanding and gender disparities in mathematics learning.

Keywords: gender differences; habits of mind; mathematics education; pseudo-understanding

Introduction

A deep and flexible understanding of math concepts is essential for students' cognitive development and academic achievement. According to Sadler and Thorning (2004), genuine mathematical comprehension requires students to establish meaningful connections between concepts rather than viewing them as isolated facts. This type of understanding fosters logical reasoning, problem-solving skills, and the ability to transfer knowledge across multiple aspects (Braithwaite & Sprague, 2021; Kusmaryono et al., 2020). However, in actual classroom practice, many students exhibit what Sadler and Thorning (2004) term as "pseudo-understanding," which refers to a condition in which learners seem to understand mathematical ideas on the surface but have difficulty applying these concepts in new or unfamiliar situations (Van Hoof et al., 2021; Zuhriawan et al., 2024). This pseudo-understanding is particularly concerning because it inhibits long-term conceptual mastery and hinders the development of mathematical reasoning (Kshetree et al., 2021; Yang & Lu, 2021), a concern that

Sadler and Thorning emphasize when discussing the difference between procedural knowledge and true conceptual understanding.

Pseudo-comprehension often arises when students emphasize procedural fluency, such as memorizing steps and formulas, while failing to internalize the underlying mathematical concepts (Hurrell, 2021). Abbott (2001) argues that meaningful mathematical understanding involves more than procedural knowledge; it requires the development of a conceptual framework that allows students to apply their knowledge in various contexts flexibly. This perspective highlights the importance of pedagogical approaches that encourage metacognitive reflection, conceptual comprehension, and engagement with authentic problem-solving experiences (Boran & Karakuş, 2022; Smortchkova & Shea, 2020). Abbott's emphasis on conceptual depth aligns with the growing attention to habits of mind in mathematics education, which refer to cognitive dispositions such as perseverance, flexibility, and critical thinking (Fatra et al., 2022; Laviona, 2024). These dispositions support students in constructing lasting and transferable mathematical understanding.

Students with strong mind habits tend to be more effective at navigating complex math challenges, promoting deep reflection, curiosity, and a willingness to grapple with uncertainty (Prasad, 2020; Tashtoush et al., 2022). Costa and Kallick (2008), in their seminal work Learning and Leading with Habits of Mind, define these habits as dispositions that empower students to behave intelligently when confronted with problems where solutions are not immediately apparent. Their framework identifies 16 essential characteristics, including persistence, metacognition, and flexible thinking, which are crucial for mathematical proficiency. In addition, recent empirical studies have shown that integrating habits of mind into instructional design can significantly reduce the occurrence of pseudo-comprehension (Dolapcioglu & Doğanay, 2022; Sari & Darhim, 2020), validating Costa and Kallick's (2008) assertion that these habits are fundamental to meaningful learning. In particular, cognitive traits such as questioning assumptions, strategically planning, and evaluating various paths can foster a complete understanding and reduce pseudo-understanding of learning materials (Purnomo et al., 2024; Widodo et al., 2021), reflecting the practical application of Costa and Kallick's theoretical framework.

An equally important but often overlooked dimension in this issue is gender. Gallagher and Kaufman (2005) argue that gender influences mathematical learning through the interplay of cognitive and sociocultural factors. Supporting this view, several studies have documented that male and female students may differ in how they engage with mathematics, shaped by individual strategies and cultural expectations (Cvencek et al., 2021; Rodríguez et al., 2020). For instance, Gallagher and Kaufman emphasize that female students often report lower self-efficacy and greater anxiety in mathematics due to prevailing stereotypes, which can hinder the development of strong mathematical habits (Heyder et al., 2021; Rossi et al., 2022). These gender-based differences significantly affect students' attitudes, depth of understanding, and vulnerability to pseudo-understanding (Mejía-Rodríguez et al., 2021), highlighting the importance of gender-sensitive approaches in mathematics education.

Therefore, creating an inclusive classroom environment that recognizes and adapts to gender dynamics has become a significant concern in mathematics education. Forgasz and Rivera (2012) argue that educational practices must actively promote gender equity by recognizing and valuing diverse approaches to mathematical thinking. When teachers provide fair opportunities and foster positive thinking habits, students across gender identities can develop more balanced confidence and mathematical competence (Sa'diyah et al., 2024; Wang, 2020). Such an environment is essential to enable all learners to engage meaningfully with math tasks and to avoid their weak understanding of math learning (Levine & Pantoja, 2021; Sovey et al., 2022). Research has shown that inclusive classrooms promote academic success and increase student engagement and motivation, especially for underrepresented gender groups, by reducing the threat of stereotypes and promoting a growth mindset. Forgasz and Rivera (2012) emphasize that gender differences in math performance are often exacerbated by societal expectations and educational biases, which can be reduced when teachers actively address these gaps through inclusive teaching strategies (Cvencek et al., 2021; Dersch et al., 2022; Rodríguez et al., 2020).

Furthermore, integrating culturally responsive pedagogy with habits of mind has emerged as a promising approach in increasingly diverse classrooms. Kallick and Zmuda (2017) advocate for personalized learning approaches that honor students' diverse backgrounds and learning needs. They argue that engagement and comprehension significantly improve when learning experiences are tailored to students' cultural contexts. Using students' cultural backgrounds, contextualizing mathematics learning has increased relevance, engagement, and conceptual clarity (Abtahi & Planas, 2024). When paired with mind-developing habits, culturally rich learning can empower students to cognitively and affectively navigate math, potentially lowering the risk of pseudo-comprehension (Cardino & Ortega-Dela Cruz, 2020; Guo & Leung, 2021). This approach aligns with Kallick and Zmuda (2017) vision of creating student-centered learning environments that simultaneously develop habits of mind and honor cultural diversity.

In addition to pedagogical and sociocultural factors, a technology-enhanced learning environment can significantly support the development of conceptual understanding when used strategically. Hank et al. (2019) explore how technological tools can be integrated effectively into mathematics instruction to develop mathematical thinking skills and habits of mind. They argue that when thoughtfully implemented, technology can make abstract mathematical concepts more accessible and engaging. For example, interactive tools and simulations can provide dynamic representations that help clarify abstract mathematical concepts, making them more accessible to students (Banda & Nzabahimana, 2021; Kaplar et al., 2022). Additionally, when these technologies are integrated with instructional strategies that promote habits of mind, such as critical thinking and problem-solving, they can create flexible, student-centered learning paths that meet diverse learning needs (Hebebci & Usta, 2022). This approach aligns with Hanks et al.'s (2019) vision for technology-enhanced mathematics education.

Given these diverse influences, this study explores the role of thought habits and gender differences in shaping students' understanding of mathematics, with particular attention to the risk of pseudo-understanding. W. Allen and C. Allen (2003) posit that intellectual habits are essential for educational excellence and equity, a framework that aligns with recent findings on how thinking dispositions influence mathematical comprehension (Wang et al., 2020). This study examines how these dispositions and gender-based learning profiles affect pseudo-comprehension in mathematics. Specifically, it seeks to answer the following questions: How do students' thinking dispositions influence their tendency toward pseudo-understanding in mathematics? In what ways do gender-related learning patterns intersect with these dispositions to shape authentic comprehension? By investigating this intersection, we aim to develop instructional strategies promoting authentic, critical, and equitable mathematics learning that minimizes pseudo-understanding and fosters inclusive classroom environments for all learners.

Literature Review

This literature review examines three interrelated domains central to the present study: pseudo-understanding in mathematics learning, the role of Habits of Mind in fostering conceptual understanding, and the influence of gender differences on learning outcomes. These areas are explored to provide a comprehensive theoretical foundation for understanding how students' thinking dispositions and gender-related learning characteristics may contribute to or mitigate the tendency toward pseudo-understanding. By synthesizing key findings from prior research, this review highlights how pedagogical strategies informed by cognitive habits and gender sensitivity can enhance authentic mathematical comprehension and promote more equitable classroom practices.

Pseudo-understanding in mathematics learning

The phenomenon of pseudo-understanding in mathematics learning refers to the condition when students seem to master the material but do not understand the concepts in depth. According to Sadler and Thorning (2004), true mathematical understanding is characterized by the ability to relate abstract concepts to concrete representations and their applications, whereas pseudo-understanding only includes surface knowledge without meaningful connections. Abbott (2001) reinforces this view by emphasizing that authentic mathematical understanding includes recognizing patterns, generalizing, and applying concepts in various contexts, a skill not found in pseudo-understanding.

Costa and Kallick (2008) argue that developing "habits of mind", including perseverance, flexibility of thinking, and metacognition, is an important foundation for overcoming pseudo-understanding in mathematics. Without such thinking habits, students memorize formulas and algorithms without understanding their conceptual essence. Hanks et al. (2019) distinguish between thinking like mathematicians involving logical reasoning and creative problem-solving and simply following mathematical procedures without a deep understanding. W. Allen and C. Allen (2003) underline that pseudo-understanding often develops in an educational environment that is more concerned with the result than the mathematical thinking process.

In everyday learning, students with pseudo-understanding can solve problems procedurally appropriately, but have difficulty explaining the reasons behind the steps they take or applying concepts in different contexts (Braithwaite & Sprague, 2021; Hurrell, 2021). This condition often arises due to a learning approach that emphasizes memorization of formulas and algorithms rather than the development of conceptual understanding (Kusmaryono et al., 2020). Van Hoof et al. (2021) emphasized that pseudo-understanding is a significant obstacle in mathematics learning because students fail to build bridges of mathematical meaning. Furthermore, Kshetree et al. (2021) revealed that students with pseudo-understanding are prone to difficulty answering questions requiring high-level reasoning or cross-contextual application, so their learning outcomes are unsustainable. Thus, pseudo-understanding represents a fundamental challenge in mathematics education at various levels of education (Zuhriawan et al., 2024).

Habits of mind and their role in conceptual understanding

To overcome pseudo-understanding, the cultivation of Habits of Mind or thinking habits emerged as an increasingly developing strategy. Costa and Kallick (2008) conceptualize Habits of Mind as an intelligent behavioral disposition manifested when individuals face complex problems. The concept includes 16 key characteristics: perseverance, impulsivity control, thinking flexibility, metacognition, and thinking interdependence. Furthermore, Costa and Kallick (2009) elaborate that Habits of Mind go beyond mere cognitive strategies. They are an intellectual behavior pattern that facilitates the development of adaptive and effective problem-solving capacity. They emphasized the importance of systematically integrating these thinking habits into the curriculum to build deep conceptual understanding. W. Allen and C. Allen (2003) also stated that Habits of Mind are an essential foundation for academic excellence. They encourage students to reflect on the thinking process and develop a more structured approach to learning.

In mathematics education, Hanks et al. (2019) elaborate on how mathematical thinking should involve cultivating certain mental habits, such as pattern identification, assumption evaluation, and logical argument construction. They argue that developing mathematical thinking habits improves academic performance and transforms students' perspectives and interactions with mathematical concepts. Kallick and Zmuda (2017) expand this concept by advocating for Habits of Mind-based personal learning, which positions students as active agents in the development of conceptual understanding. Sommers (2010) presents a practical framework for educators in facilitating the development of Habits of Mind in mathematics learning, emphasizing modeling, directed reflection, and specific feedback.

In implementing education, Habits of Mind facilitates students in responding to mathematical problems reflectively and strategically (Fatra et al., 2022; Maarif & Fitriani, 2023). In this context, the focus of learning is not only on the final result but also on the thought process that is undertaken. Cultivating thinking habits through problem-based learning, reflection, and open dialogue improves students' conceptual understanding (Dolapcioglu & Doğanay, 2022; Purnomo et al., 2024). Various studies confirm that the development of mathematical thinking habits is positively correlated with improved mathematical reasoning skills and problem-solving skills (Laviona, 2024; Prasad, 2020; Tashtoush et al., 2022). Thus, Habits of Mind serve as a cognitive disposition and a fundamental foundation in constructing meaningful and sustainable mathematical understanding.

Gender differences and their implications for pseudo-understanding

Gender plays an important role in the emergence of pseudo-understanding in mathematics learning. Gallagher and Kaufman (2005) explain that biological factors do not solely cause gender differences in mathematical understanding but result from complex interactions between social experiences and educational expectations. Parker et al. (1996) add that gender stereotypes create different expectations of male and female students, implicitly affecting their engagement and learning approach. This condition can encourage some students, especially women, to adopt learning strategies that do not support conceptual understanding, making them more susceptible to pseudo-understanding.

Forgasz and Rivera (2012) propose a theoretical framework highlighting the interaction between institutional and pedagogical factors and gender identity in shaping students' mathematical experiences. When learning is not sensitive to gender issues and instead reproduces existing stereotypes, the potential for pseudo-understanding to emerge is higher. This is in line with the findings of Hottinger (2016), who showed that cultural representations of who is considered a mathematician can create implicit barriers, particularly for female students, in identifying with mathematics and developing a wholesome conceptual understanding.

Empirical support for this view comes from the National Research Council (2010), which identified systemic gender differences at critical transition points in mathematics education. Although the academic achievement of male and female students tends to be equal, differences in self-perception and mathematical ability efficacy contribute to how they build understanding. Female students, for example, are more prone to experiencing math anxiety and have lower self-efficacy than male students (Heyder et al., 2021; Rodríguez et al., 2020; Wang et al., 2020), which has an impact on their involvement in higher-level thinking activities. In contrast, male students often show high self-confidence, but risk relying on superficial procedural approaches.

Recent research also confirms that gender stereotypes in society significantly affect how students respond to math learning (Cvencek et al., 2021; Dersch et al., 2022; Rossi et al., 2022). Cross-cultural findings suggest that the gap in mathematical self-concept between male and female students is universal (Mejía-Rodríguez et al., 2021). Therefore, applying a gender-responsive learning approach is crucial to support equitable cognitive development, including forming Habits of Mind that can strengthen students' conceptual understanding (Abtahi & Planas, 2024; Levine & Pantoja, 2021).

Pedagogical approach and implications of educational practice

A practical pedagogical approach to overcoming pseudo-understanding requires the integration of deep learning theories. Costa and Kallick (2009) developed a Habits of Mind framework that prioritizes the importance of modeling, reflection, and continuous assessment in developing productive thinking dispositions. This approach also pays attention to the social and cultural context of students, as proposed by Vygotsky (1978), who emphasizes the role of social interaction in cognitive development, or by J. Banks and C. Banks (2016), who proposes an education that is responsive to cultural diversity in order for mathematics learning to be more relevant and inclusive.

Hanks et al. (2019) emphasize the importance of strategies that encourage students to think like mathematicians through experimentation, logical reasoning, and mathematical communication to build a deep understanding. In line with that, Forgasz and Rivera (2012) and Parker et al. (1996) remind that associating mathematics learning with students' life experiences can increase the relevance of learning, especially in addressing gender issues. Sommers (2010) also points out the important role of teachers in creating a reflective culture that develops productive thinking habits, which plays an important role in avoiding pseudo-understanding. On the other hand, Kallick and Zmuda (2017) introduced the concept of personalized learning, which allows students to define their own content and learning process, overcoming procedural learning that often gives rise to pseudo-understanding. This approach is increasingly relevant in contemporary education, emphasizing responsiveness to students' cultural diversity.

Furthermore, various studies confirm that Habits of Mind and gender differences play an important role in forming adaptive and effective instructional strategies in mathematics learning (Cardino & Ortega-Dela Cruz, 2020; Sáiz-Manzanares et al., 2021). Creating an inclusive and gender-sensitive learning environment minimizes misconceptions and increases student participation (Dersch et al., 2022; Rodríguez et al., 2020). Differences in self-concept and attitudes towards mathematics influenced by gender can significantly impact students' engagement and academic performance (Cvencek et al., 2021; Mejía-Rodríguez et al., 2021). Therefore, pedagogical practices that foster a positive thinking disposition through Habits of Mind can form a reflective and supportive classroom environment and help all learners develop balanced confidence and mathematical competence (Laviona, 2024; Prasad, 2020).

Methodology

Research design and approach of the study

This study employs a mixed methods approach with an explanatory sequential design, which involves collecting and analyzing quantitative data in the first phase, followed by qualitative data collection and analysis to elaborate on the quantitative findings (Creswell & Plano Clark, 2018; Johnson & Christensen, 2020). This design was chosen for its flexibility in providing a comprehensive understanding of the phenomenon of pseudo-understanding in mathematics by combining the strengths of both quantitative and qualitative data (Cohen et al., 2005; Tashakkori et al., 2021). It is particularly appropriate for research exploring complex educational constructs, as it allows the initial quantitative results to guide the selection of participants and focus areas in the qualitative phase (J. Creswell & D. Creswell, 2023).

In this study, the quantitative phase aims to identify patterns in students' mathematical understanding, habits of mind, and gender differences, which are chosen as focal points because they are closely related to the phenomenon of pseudo-understanding in mathematics, the central focus of this research. Identifying such patterns is essential for revealing surface-level comprehension and uncovering the cognitive and dispositional factors contributing to students' mathematical learning. Prior research supports the significance of these dimensions; for instance, habits of mind such as persistence, flexibility, and metacognitive awareness have been found to play a crucial role in deep mathematical understanding (Nopriana et al., 2023), while gender-related differences may influence students' mathematical reasoning processes and engagement (Phillips, 2024). The results of the quantitative phase then inform the qualitative phase, where in-depth interviews are conducted with purposefully selected male and female students. This phase is designed to investigate aspects that statistical analysis alone may not fully explain, such as students' personal strategies, cognitive biases, or contextual influences in problem-solving. Through this sequential process, the study seeks to provide a more nuanced and holistic explanation of how pseudo-understanding manifests in mathematics education and how it may be shaped by both gender and individual dispositions.

Research site and participants

The participants of this study were first-semester students from a Mathematics Education program at a public university in Indonesia. This group was selected purposively as they transitioned from secondary to higher education, a phase often marked by significant cognitive and epistemological development that influences how students engage with abstract concepts (Hofer & Pintrich, 2022). At this stage, learners are particularly susceptible to pseudo-understanding due to their evolving ability to process complex mathematical reasoning (Vygotsky, 1978). A purposive sampling technique was employed to ensure representation across genders and diverse academic backgrounds, enabling the researchers to select individuals with direct and relevant experiences related to the research focus (Creswell & Plano Clark, 2018; Patton, 2015). A total of 57 students participated in the quantitative phase, from which six were purposefully selected for the qualitative phase using a maximum variation strategy, which is recommended for capturing contrasting profiles and enhancing the richness of qualitative insights (Miles et al., 2014).

Data collection and analysis

Data collection in this study used three main instruments: a test of understanding of mathematical concepts, a questionnaire of thought habits, and a demographic identity sheet. The concept comprehension test measures students' conceptual and procedural understanding of fundamental mathematics (Dumontheil et al., 2022; Zacharopoulos et al., 2021), as recommended in educational research for capturing both surface and deep learning outcomes (Fraenkel et al., 2019). Meanwhile, the mind habits questionnaire was adapted from various recent research indicators that focus on thinking habits in mathematics learning, covering aspects of perseverance, cognitive flexibility, reflection, and impulse management (Curelaru et al., 2022; Tashtoush et al., 2022).

Before being used, the research instruments were validated by three mathematics education experts to ensure content validity and construct clarity. This process followed a systematic statistical and expert-based validation approach, emphasizing both face and content validity as outlined by Ary et al. (2010) and Fraenkel et al. (2019). The data collection process was carried out in two stages. The first stage was quantitative, where data were collected through online tests and questionnaires using the Google Forms platform (Zarouali et al., 2023). The collected data were then analyzed descriptively to identify groups of students based on their pseudo-understanding and habits of mind. This aligns with J. Creswell and D. Creswell's (2023) recommendation to use descriptive statistics in the initial phase of explanatory sequential mixed methods.

In the second qualitative stage, semi-structured interviews were conducted online through the Zoom platform to explore the students' thinking processes more deeply. Qualitative data analysis employed a thematic approach as guided by Saldaña (2016), involving iterative coding and categorization of meaning units. To maintain research validity, techniques such as source triangulation, peer debriefing, and member checking were applied, consistent with standards for qualitative rigor described by Patton (2015). Using this mixed-method approach allows researchers to understand the relationship between mind habits, gender, and pseudo-understanding in mathematics learning (Dawadi et al., 2021), and follows a comprehensive design structure for integrating both numerical trends and lived experiences (Creswell & Plano Clark, 2018).

Results

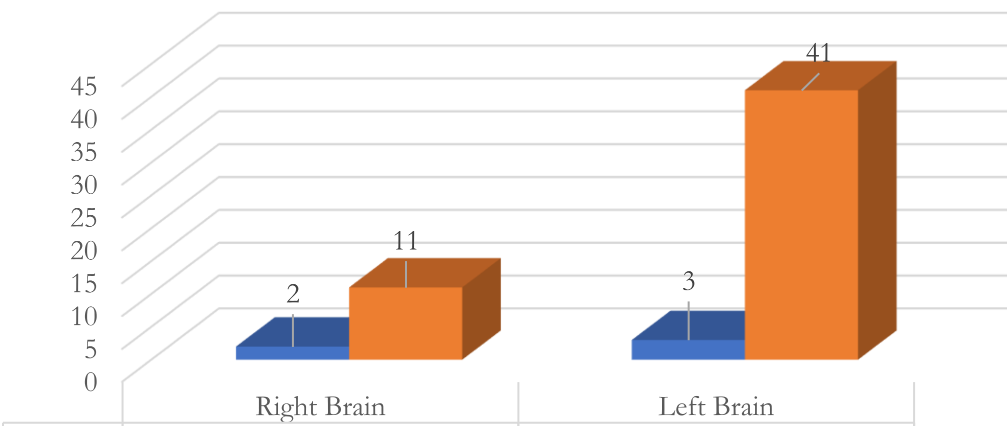
Pseudo-understanding based on habits of minds and gender

This study reveals several important findings related to the cognitive profile of students, especially in terms of the tendency to dominate the brain hemispheres, the level of understanding of mathematical concepts, and the existence of pseudo-understanding. These three aspects were analyzed in an integrated manner to gain a deeper understanding of how the characteristics of brain dominance are related to the quality of conceptual understanding of mathematics education students in the first semester.

The data analysis results showed that most students in this study tended to dominate the left brain. This distribution pattern can be seen in all participants, consisting of five male and 52 female students. However, the stark difference in number between the two groups needs to be carefully considered so as not to cause inaccurate generalizations.

As shown in Diagram 1, three of the five male students were left-brained, while the other two showed right-brain dominance. Meanwhile, of the 52 female students, as many as 41 people have left-brain dominance, and 11 others are right-brain-dominant. These findings suggest that the tendency to dominate the left brain is more common in mathematics education students, both in the male and female groups.

Diagram 1. *Distribution of dominance of student brain hemispheres by gender*



	Right Brain	Left Brain
Male	2	3
Famale	11	41

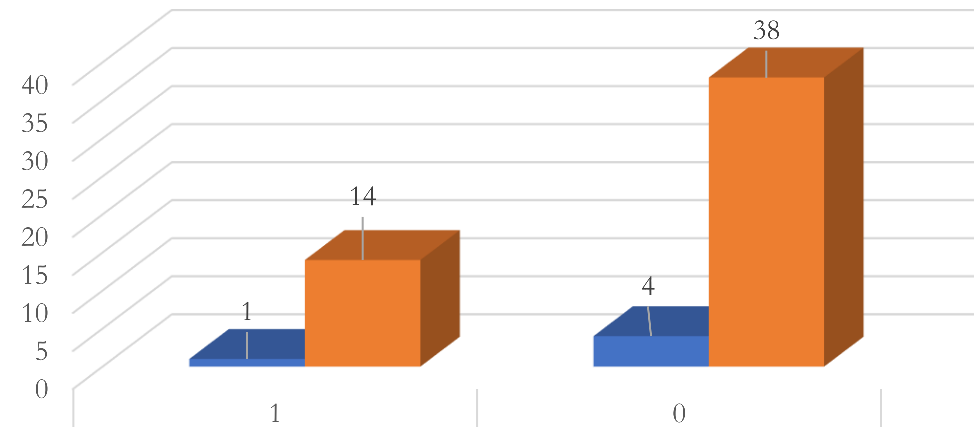
Judging from the percentage, the left brain is more dominant in male and female students. This dominance is related to a logical, systematic, and analytical way of thinking. However, because male students are much smaller than female students, comparisons between genders must be done carefully. In this study, the dominance of the left brain is more commonly found, especially in female students who are more numerous.

Although the number of male students is small, the results show that most mathematics education students tend to think logically and analytically, which is characteristic of the left brain. This suggests that math learning focusing on logic and analysis may be better suited for most students. However, the difference in the number of male and female respondents hinders the study. Therefore, further research with a more balanced number of participants is needed to see the difference in the way of thinking between men and women. The dominance of the left brain in this study is by the characteristics of mathematics students who think analytically, logically, and systematically. However, the dominance of one side of the brain does not automatically guarantee a deep understanding of mathematics.

Analysis of the conceptual comprehension test results shows that only a small percentage of students can answer questions correctly and thoroughly. Of the five male students, only one answered correctly, while the other four made mistakes. Meanwhile, of the 52 female students, as many as 14 gave the correct answer, and 38 others made mistakes. Thus, the error rate is 80 percent for male students and 73 percent for female students. These findings suggest that the dominance of logical and systematic thinking styles does not always correlate positively with success rates in understanding mathematical concepts.Additional details of the themes above are given below.

ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 1 | June 2025|

Diagram 2. *Frequency of true and false answers by gender*



	1	0
Male	1	4
Famale	14	38

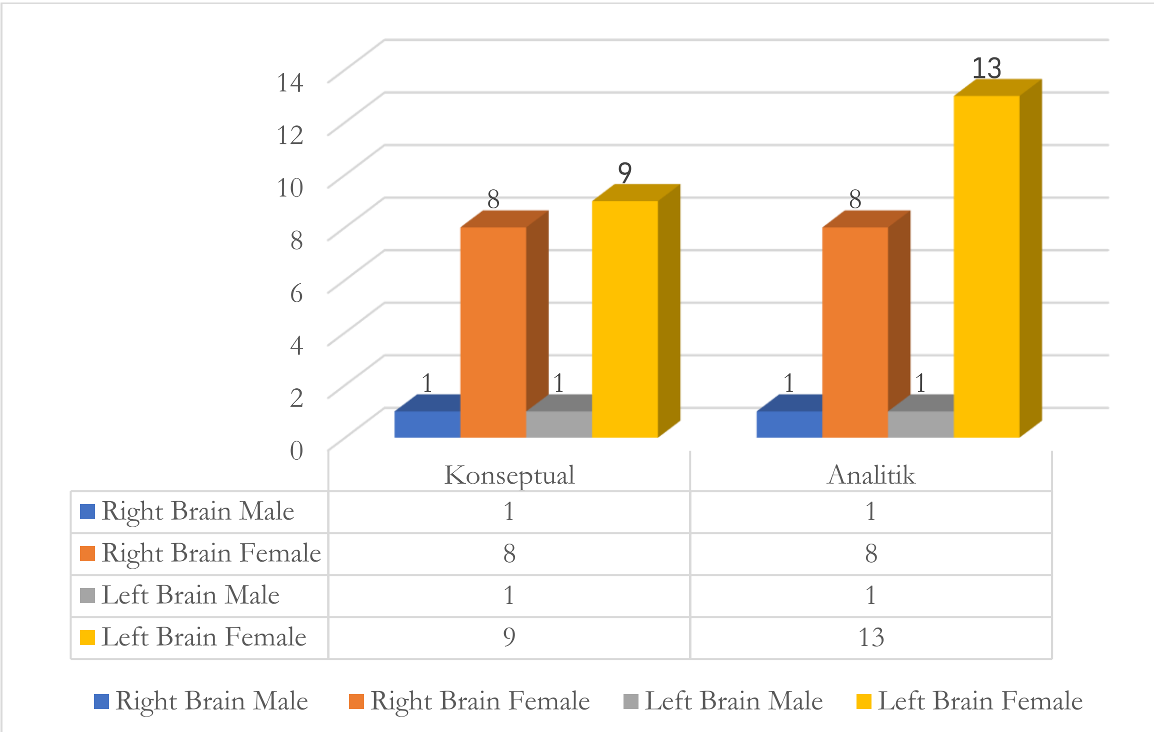
The higher number of errors in female students does not mean that they are more often wrong than male students. This happens because the number of female students is much larger. So, the error rate in doing math problems is high in all male and female students. The errors found take various forms. Some use methods not based on the problem, misunderstand information, misinterpret mathematical symbols, miscalculate them, and misinterpret algebra. Many students also immediately make conclusions without the correct thought process.

These findings show that students are weak in understanding concepts and procedures. This possibility is due to a way of learning that relies too much on memorizing formulas without understanding their meaning. Developing a teaching method that emphasizes understanding concepts, the use of images, and the relationship between mathematical concepts is necessary. That way, students are expected to be able to apply their knowledge better when working on complex math problems. Furthermore, error analysis shows the existence of pseudo-understanding, a condition where students seem to understand a concept when they do not. This pseudo-understanding is seen in two ways: conceptual understanding and analytical skills.

In the conceptual dimension, pseudo-understanding symptoms were found in one male student with right-brain dominance, eight female students with right-brain dominance, one left-brained dominant male student, and nine left-brained female students. Meanwhile, in the analytical dimension, the number of pseudo-understanding cases is higher, especially in the group of female students with the dominance of the left brain, which is as many as 13 people.

ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 1 | June 2025|

Diagram 3. *Pseudo-understanding based on gender and brain dominance*



The study's results showed that students with left-brain dominance, even though they can think logically, can still experience pseudo-understanding. They are able to come up with answers that are procedurally correct but not accompanied by a deep understanding of concepts. This is especially evident in female students with left-brain dominance, who tend to show pseudo-understanding in conceptual and analytical aspects.

The left brain's dominance, which is synonymous with analytical ability, does not guarantee a thorough understanding of concepts. The ability to think logically can disguise fundamental errors if it is not accompanied by essential understanding. Although the number of male students is smaller, pseudo-understanding is still found in both brain-dominating groups.

These findings emphasize the importance of learning that assesses not only the final outcome but also the student's thought process. Students with left-brain dominance who tend to follow procedures must be encouraged to understand the concept thoroughly. Therefore, educators need to actively diagnose understanding through metacognition reinforcement, triggering questions, and thinking reflection to minimize pseudo-understanding.

Overall, these results confirm that success in mathematics learning is not only determined by biological factors or cognitive predisposition alone but also by the interaction between pedagogical approaches, affective aspects, and metacognition. Students who think systematically and logically risk experiencing pseudo-understanding if they are not guided to understand meaning and processes more deeply, which can hinder long-term conceptual development

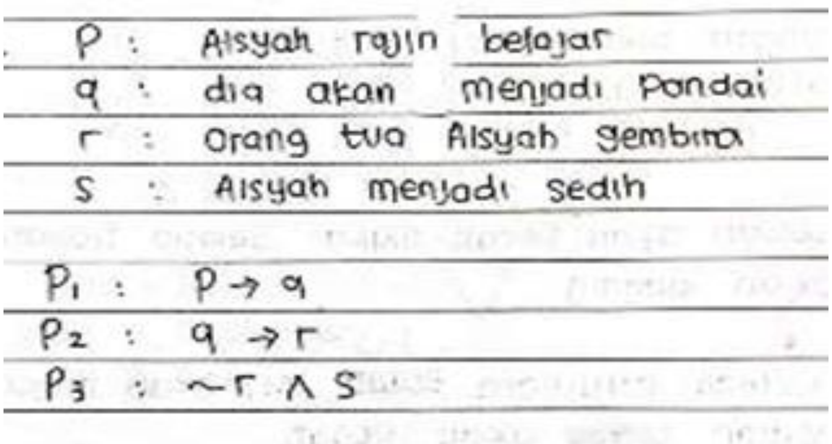
ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 1 | June 2025|

Pseudo-understanding based on test and interview data

The focus of the analysis is directed at an in-depth exploration of pseudo-understanding in the context of mathematics learning, using data from test results and interviews. This research aims to understand further how students process and apply mathematical concepts in real-world situations through a qualitative approach. The test data provides an overview of areas where students may demonstrate pseudo-understanding, while in-depth interviews investigate their way of thinking and their challenges. Combining these two data sources, the study sought to uncover the factors contributing to pseudo-understanding and how individual thinking habits and dynamics affect students' learning processes. This analysis is expected to provide richer and more contextual insights into learning strategies that can be used to address gaps in understanding among students.

In the analysis of the results of student A's work in solving mathematical logic problems related to the use of logic symbols in representing verbal statements in the following Figure 1:

Figure 1. *Student A is left brain and does not think analytically*

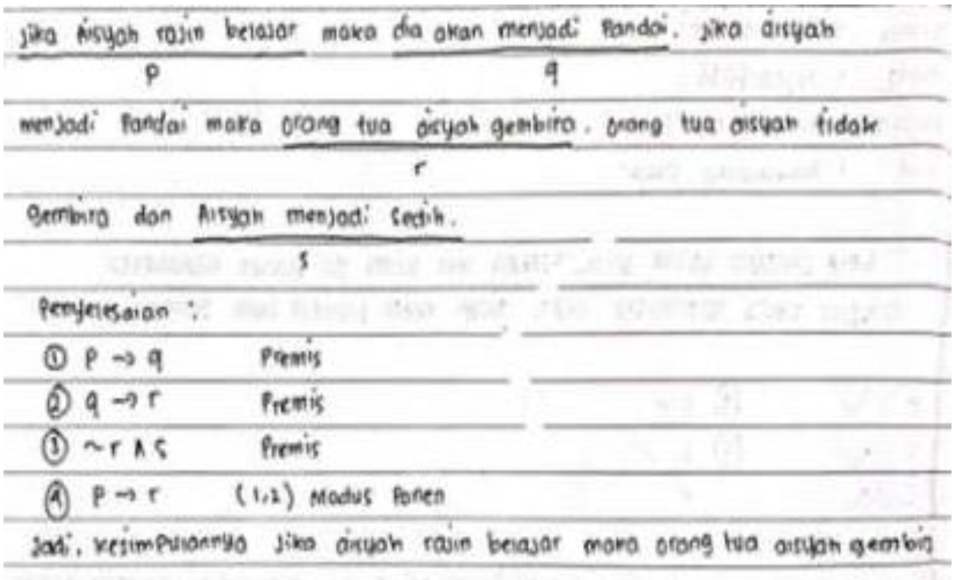


Student A is included in the category of students with left-brain dominance but only shows a pseudo-analytical understanding of logic. He can remember basic concepts such as conjunctions and implications from books and lecturer explanations but has not fully understood the relationship between concepts in problem-solving. In the interview, A explained his approach by composing a statement using logical symbols, such as the arrow (→) for 'if-then,' ∧ for 'and,' and ~ for 'not,' based on the lecturer's explanation that the arrow symbol is associated with the cause-and-effect relationship.

However, when asked further, A admitted that he only "remembered the way it was written" and felt confused about explaining the logical relationship between the statements. He also expressed difficulty concluding the already written premise, saying, "All I know is to turn the sentence into the form of logical symbols, but to draw conclusions I don't understand." In learning, A tends to memorize the shapes of symbols and rely on examples in books; remembering shapes is easier than understanding meaning. These findings show that although A can write logical symbols correctly, his conceptual understanding and applicability are still weak, so a learning approach emphasizes understanding the meaning and logical relationships between statements.

The results of other work done by student B in solving mathematical logic problems about concluding using inference rules are presented in the following Figure 2:

Figure 2. *Student B is left-brained and has partial analytical thinking*


jika Aisyah rajin belajar maka dia akan menjadi pandai. jika aisyah menjadi pandai maka orang tua aisyah gembira. orang tua aisyah tidak gembira dan Aisyah menjadi sedih.

p q r s

Penyelesaian :

① p → q Premis

② q → r Premis

③ ~r ∧ s Premis

④ p → r (1,2) Modus Ponen

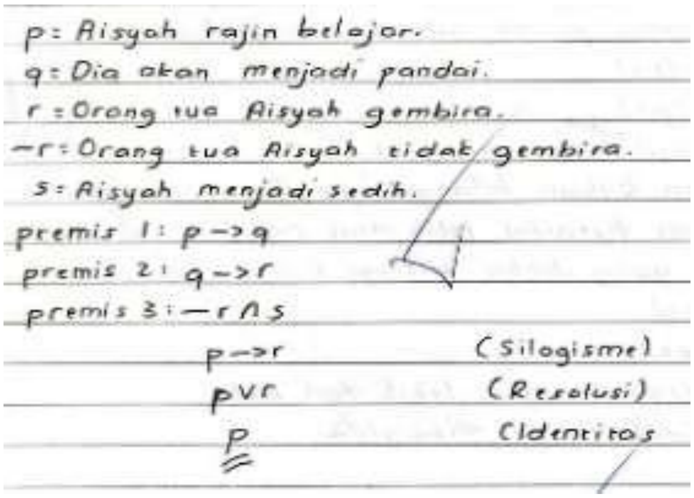
Jadi, kesimpulannya jika aisyah rajin belajar maka orang tua aisyah gembira

Based on the analysis, student B showed pseudo-analytical thinking with left-brain dominance. Despite having similarities with student A, student B is categorized as a partial analytical thinker. This can be seen from his efforts to use the ponens mode in solving problems, even though the reasons are still not precise and not supported by a strong conceptual understanding. From the results of their work, student B was able to write logical premises with the correct symbols, such as $p \rightarrow q$ for "if Aisyah is diligent in studying, then she will be smart," $q \rightarrow r$ for "if Aisha is smart, then her parents are happy," and $\neg r \wedge s$ for "Aisyah's parents are not happy, and Aisha is sad." However, his explanation does not show a deep understanding of the concept.

In the interview, student B stated that he used the ponens mode because "the lecturer said that if there is $p \rightarrow q$ and p, then it can be concluded q." Even so, he admitted that he was unsure whether the use was by the context of the question. When asked to explain the conclusion of $p \rightarrow r$, he said, "Because there are $p \rightarrow q$ and $q \rightarrow r$, I think it can be immediately concluded by $p \rightarrow r$," but could not explain the reason logically. This suggests that there is still a gap in the understanding of deductive logic. In learning, student B tends to record the lecturer's explanation and repeat it through reading and examples. He also keeps trying to work on new questions despite doubts about the answer. This attitude reflects an exemplary dedication to learning, even though the understanding of the concept is not yet fully mature. These findings could be the basis for designing more effective logic learning strategies.

Based on the evaluation of student C's answer sheet, several important information were obtained that indicated the level of student understanding, as shown in the following Figure 3:

Figure 3. Student C is right brain and partial analytical thinking

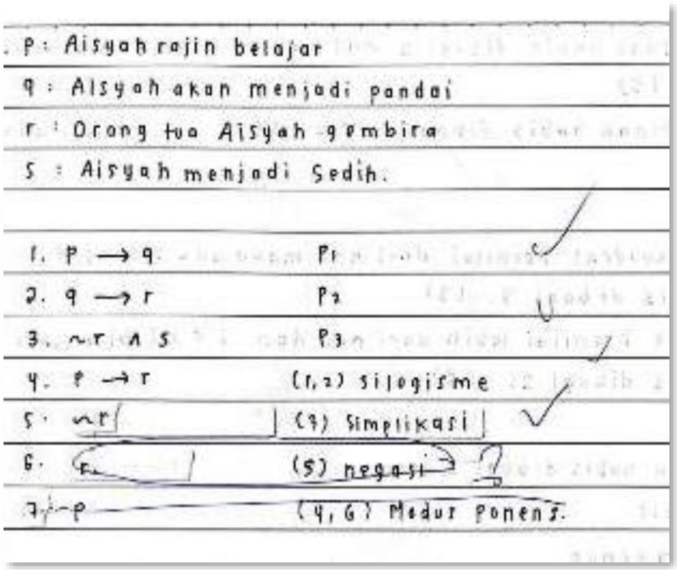


Analysis of student C's work results shows a similar approach to student B, both of which fall into the pseudo-analytical category. However, C students display their characteristics in solving problems by integrating various mathematical logic concepts, such as syllogism, resolution, and identity. Unfortunately, applying these concepts is often accompanied by inappropriate and not entirely logical arguments. From his written work, it can be seen that C attempted to connect premises such as $p \rightarrow q$, $q \rightarrow r$, and $\neg r \wedge s$ through syllogism, but he admitted that he was "a bit confused about how to apply them exactly." The use of various concepts at once is based on the desire to produce perfect answers, even though they do not fully understand the relevance of each idea in the context of the problem.

In the interview, student C stated, "I feel dissatisfied if I don't try to apply everything I learn." Despite his efforts, he felt the answer was "not strong" and had difficulty connecting theory with problems. He also realized, "I knew the theory but was still confused about how to apply it exactly," which showed a gap between declarative understanding and practical skills. The drive to keep going despite feeling unsure comes from the motivation to make the most of it; as he puts it, "At least I've tried to use all the knowledge I have." This perfectionistic attitude is also evident in completing other math tasks, where C always tries to be "perfect." However, sometimes, it makes him too focused on approaches that are not necessarily suitable.

The following are the key findings from the analysis of Student D's work that indicate their level of understanding of the material, as shown in the following Figure 4:

Figure 4. *Student D is left brain and pseudo right*



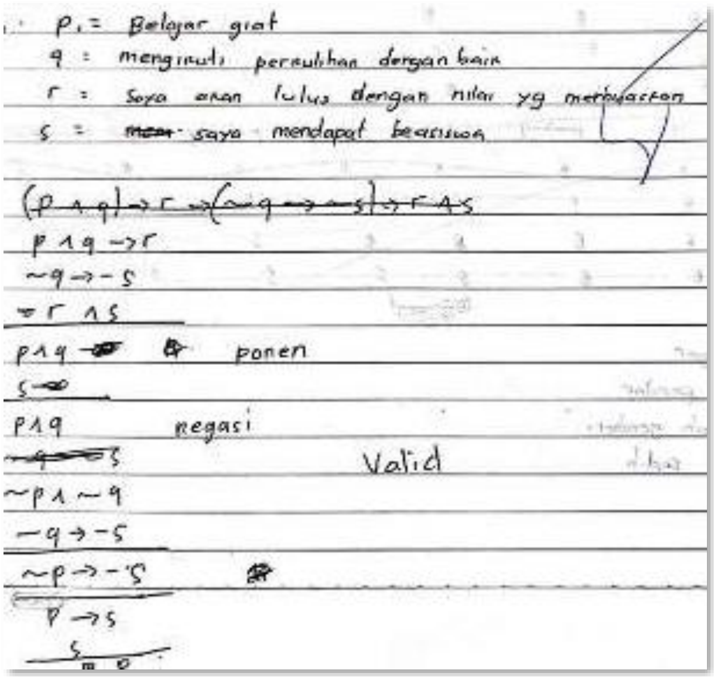
The analysis of student D's work results shows comprehensive thinking skills in solving mathematical logic problems, with a strong understanding of concepts such as implications, syllogisms, and modus ponens. Although he had experienced confusion in understanding the relationship between concepts, he could recognize and correct mistakes after reflection. His systematic and sharp approach is reflected in his ability to understand the problem in its entirety in a variety of ways. Student D also shows perseverance, is not in a hurry to find solutions, and can see problems from various perspectives, resulting in deeper understanding and solutions.

Based on the interview results, student D outlined his efforts in understanding and applying the rules of inference to test the validity of arguments. He tries to relate the cause-effect relationship in premises such as "if Aisha is diligent in her studies, then she will get good grades" and "if Aisha gets good grades, then she will get a reward from her parents," which reflects an early understanding of the logical implications. Difficulties began to arise when applying the syllogism when student D realized that the use of $r \rightarrow r$ was inappropriate, signifying the challenge of applying logic theory to a practical context. He doubts simplification, although he has sought to identify important elements of complex statements.

Confidence is more visible in using the ponens mode, as shown in his statement: "Because it is known that Aisyah is diligent in studying (p), and there is a $p \rightarrow q$ relationship, that's why I conclude q." The process of solving problems occurs indirectly; Student D states that "the most difficult thing is to determine the order of the premises to be logical," indicating a repeated search process to find the right argument structure. These findings suggest that although D students understand the theory of logical inference, the internalization of the concept is not yet fully mature. This reflects the characteristics of reflective and analytical learners, who prioritize deep understanding over speed in solving problems.

Furthermore, the analysis of the results of student E's work reveals some important findings that reflect his level of understanding, as illustrated in the following Figure 5:

Figure 5. *Student E is right brain and pseudo is wrong*



Based on the analysis results, Student E showed the characteristics of pseudo-wrong thinking. Despite having right-brain dominance, which is reflected in some positive cognitive abilities, there is a gap between conceptual understanding and implementation. Positive abilities identified include the ability to relate old knowledge to new situations, flexibility in changing the perspective of problem-solving, creativity in generating new ideas, structured written and verbal communication, and the ability to break complex problems into simpler units.

However, there are significant limitations in its conceptual understanding. Although the student claims to understand the basic concepts of logic and can represent them in mathematical symbols, the results of his work show errors in the representation. Student E shows mental processes in processing concepts and trying to identify the relationships between ideas, but the logical connections built are still artificial. Although it shows conceptual and analytical thinking, an in-depth analysis reveals a fundamental error in the understanding and application of mathematical logic concepts.

In the interview, student E explains his approach by starting from an understanding of the implications and turning the statement into a mathematical symbol. For example, P for 'study hard,' Q for 'doing well,' and R for 'graduating with satisfactory grades,' with "(P∧Q)→R" describing the relationship. However, when asked to explain the use of the negation operator, student E admitted to doubt, saying that they thought negation was necessary to prove validity but were not sure of the appropriateness of the move. This shows confusion in applying the concepts of logic that have been learned, an indication of pseudo-understanding.

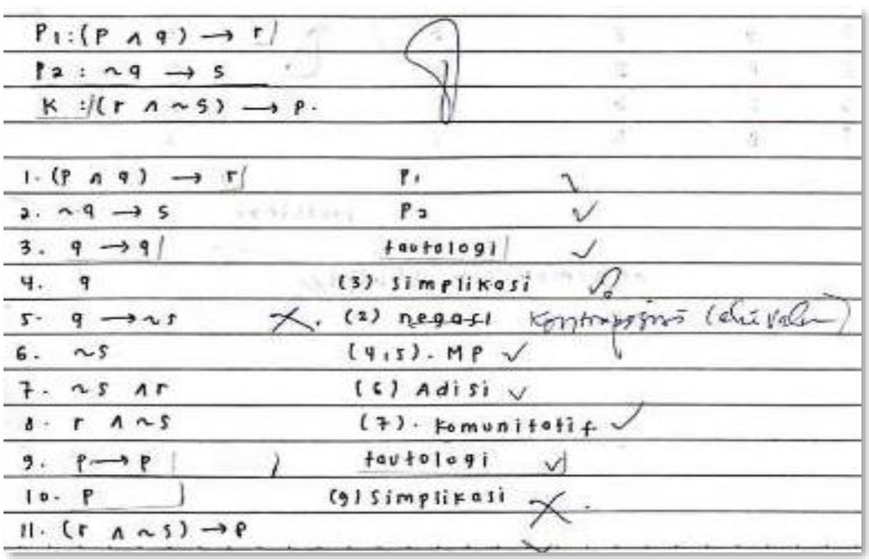
E students also stated that although the final result led to a 'valid' conclusion, they were not entirely confident in the steps taken, reflecting a lack of confidence in the problem-solving process.

When asked about the solution approach, E explained that they break the problem into small parts and use the rules of logic that are remembered but admit that some concepts are still not fully understood.

The main difficulty that E faces is explaining the logical relationship between the initial statement and the conclusion. This suggests that although they can identify the basic relationship, the internalization of logical understanding still needs to be improved. This makes it clear that conceptual understanding is not yet fully functionally internalized.

Based on the assessment of the results of the work of Student F, various aspects were found that described their level of understanding, as presented in the following Figure 6:

Figure 6. *Student F is right-brained and has a pseudo-understanding of concepts*



Analysis of the results of student F's work revealed significant difficulties in mastering the concept of mathematical logic. Student F shows limitations in controlling and integrating the concepts needed to solve problems, such as modus ponens, modus tollens, and syllogism. The main difficulty lies in the inability to establish a relationship between the basic concepts of logic and the inferential concepts. As can be seen from the results of the students' work, there are several errors in applying logical rules and making conclusions, indicating a gap in understanding in connecting these concepts.

In the interview, student F explained his approach by trying to apply the rules that had been learned. In questions 1 to 3, F uses the ponens mode correctly, explaining that "if p then q, and p is true, then q is also true."

However, difficulties arose in questions 4 and 5, where F admitted that he was confused about connecting the premises to reach the correct conclusion. F stated difficulties in distinguishing when to use the ponens mode and the tollens mode and confusion in applying the syllogism rules. This suggests confusion when applying more complex logic concepts, indicating pseudo-understanding.

When faced with complex problems, F immediately applies the remembered rules without breaking down the problem first, often causing errors. F also rarely double-checks the answers, immediately proceeding to the next question without ensuring the accuracy of the logic used.

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F students usually only use one understood way of solving without looking for other alternatives. To improve his understanding of mathematical logic, F realized the need for more practice and understanding of the relationships between concepts and learning to be more thorough and systematic in working on problems. This shows that deep internalization of concepts is still needed despite the basis of understanding.

Discussion

This study revealed a pattern of left-brain dominance that is quite prominent among first-semester mathematics education students, with 77.19% of the total 57 participants showing left-brain dominance. This pattern is consistent in both genders, although higher in female students. The high error rate in both left- and right-brained students indicates that certain cognitive predispositions do not guarantee the ability to understand concepts fully. These findings support previous research conducted by Hurrell (2021), who emphasized that conceptual and procedural knowledge must be developed in tandem rather than relying on cognitive styles alone, and Wang (2020), who found that cognitive factors beyond hemispheric dominance play critical roles in mathematical achievement and understanding.

Furthermore, the analysis of student error patterns reveals the existence of pseudo-understanding, a condition in which students appear to understand the material but lack conceptually correct understanding. This phenomenon has been widely reported in the literature as a form of misconception difficult to identify because students can solve problems procedurally, as found in studies conducted by Kusmaryono et al. (2020) and Van Hoof et al. (2021). Pseudo-understanding in this study appears in two main dimensions: conceptual and analytical. A total of 19 students showed pseudo-understanding in the conceptual dimension, and most of them came from the female group with both left and right brain dominance. In the analytical dimension, most cases were found in the dominant group of left-brained women. This strengthens the hypothesis that high logical-analytical skills can mask misunderstandings, allowing students to devise problem-solving procedures that appear correct without being based on deep conceptual understanding. This hypothesis is also supported by recent research conducted by Zuhriawan et al. (2024) and Kshetree et al. (2021).

Further analysis through six case studies showed variations in the manifestations of pseudo-understanding. Some students, although they seem to have mastered procedures and symbols, admit they only remember the presentation form without understanding its meaning. This aligns with research conducted by Yang and Lu (2021) and Hurrell (2021), which shows that understanding based primarily on memorization can lead to a false sense of mastery over the material. These cases demonstrate how students with both left and right brain dominance experience a gap between declarative and procedural knowledge. As emphasized in research conducted by Braithwaite and Sprague (2021), this gap represents one of the key factors hindering deep conceptual understanding. Some students attempt to integrate concepts but struggle with application and justification, while others show better understanding because they can reflect on correcting mistakes. This demonstrates the importance of metacognition, which significantly influences conceptual understanding and improvement. These findings align with research conducted by Smortchkova and Shea (2020) and Boran and Karakuş (2022) that emphasize the crucial role of metacognition in mathematics learning.

The implications of these findings are significant for the practice of teaching mathematics in colleges. The high prevalence of pseudo-understanding shows that learning approaches should not be oriented solely toward results but must focus on thinking processes and conceptual meaning. Learning strategies based on visual representation, exploration of connections between concepts, and strengthening metacognitive awareness must be reinforced. This is supported by recent research conducted by Fatra et al. (2022) and Laviona (2024), demonstrating the effectiveness of such approaches in enhancing students' conceptual understanding. The variation in the manifestation of pseudo-understanding also suggests that learning approaches must be adaptive and accommodate students' different ways of thinking. As emphasized in research conducted by Cardino and Ortega-Dela Cruz (2020) and Guo and Leung (2021), understanding diverse learning styles is essential in designing effective mathematics learning experiences. Additionally, reflective learning experiences that encourage students to evaluate their thinking processes can help prevent misunderstanding illusions, as Sáiz-Manzanares et al. (2021) indicated.

Gender differences in mathematical understanding and attitudes also emerged as an important factor in this study. The higher prevalence of pseudo-understanding among female students with left-brain dominance aligns with research on gender differentials in mathematics self-concept and disposition. This is reinforced by research conducted by Cvencek et al. (2021) and Mejía-Rodríguez et al. (2021) that deeply examines factors influencing gender differences in mathematics learning. These findings suggest the need for gender-sensitive approaches in mathematics education that address procedural fluency and conceptual understanding, as suggested by Rodríguez et al. (2020) and Heyder et al. (2021).

Developing mathematical habits of mind and mathematical reasoning should be prioritized in instruction to address the challenges of pseudo-understanding. Research by Maarif and Fitriani (2023) and Prasad (2020) demonstrates that developing mathematical thinking habits can significantly improve students' conceptual understanding. Strategies such as problem-based learning as researched by Purnomo et al. (2024), integration of computational thinking as studied by Jong et al. (2020) and Sovey et al. (2022), and the use of interactive learning materials as tested by Kaplar et al. (2022) and Banda and Nzabahimana (2021) can help students develop deeper conceptual understanding alongside procedural fluency.

Overall, this study shows that success in learning mathematics is influenced by brain hemisphere dominance and other factors such as learning strategies, learning experiences, and metacognitive abilities. Left brain dominance in student profiles does not necessarily guarantee deep understanding and can instead mask weaknesses in conceptual meaning. Therefore, a more holistic approach to learning is needed, emphasizing procedure and encouraging authentic conceptual understanding. This aligns with research findings by Tashtoush et al. (2022) and Dolapcioglu and Doğanay (2022), showing that integrated approaches in mathematics learning can effectively address the gap between procedural and conceptual understanding.

Despite the significant findings, this study has several limitations that warrant consideration. First, the study was limited to 57 first-semester students from a single mathematics education program at one institution, constraining the generalizability of results to broader populations (J. Creswell & D. Creswell, 2023). Second, this research was conducted during the early stages of students' academic journey, which may not fully reflect their comprehensive cognitive and metacognitive development over time. The cross-sectional design also prevented examination of how pseudo-understanding patterns might evolve as students progress through their studies.

Third, this study concentrated primarily on brain dominance and error patterns without considering other potentially influential variables such as students' academic backgrounds, prior learning experiences, socioeconomic factors, or specific instructional approaches they received. These variables could significantly affect conceptual understanding (Johnson & Christensen, 2020; Lugina &

Oktaviana, 2023). Fourth, identifying pseudo-understanding relies on analyzing student responses and reflections, which may be subject to interpretive bias or influenced by students' ability to articulate their thinking processes. Additionally, while validated, the brain dominance assessment tool represents a simplified categorization of complex cognitive processes.

Finally, conducting the study within a single institutional context may limit the applicability of findings to different educational environments with varying teaching cultures, resources, or student demographics. Future research would benefit from employing longitudinal approaches, expanding samples across multiple institutions, incorporating diverse educational contexts, and considering additional variables that influence mathematical understanding to achieve more comprehensive and nuanced insights into the phenomenon of pseudo-understanding in mathematics education.

Further research can focus on metacognition, mathematical self-efficacy, and previous learning experiences in shaping student understanding and developing learning interventions to address pseudo-understanding more effectively. As suggested by research conducted by Hashim et al. (2021) and Goren and Kaya (2023), strategies focusing on developing metacognitive awareness and positive attitudes toward mathematics have great potential for addressing challenges in mathematical conceptual understanding.

Conclusion and Recommendations/Implications

This study examined the relationship between brain hemisphere dominance and pseudo-understanding patterns among first-semester mathematics education students. The findings reveal several key insights that address the research questions posed at the beginning of this investigation. Regarding brain dominance patterns, the study found that 77.19% of participants exhibited left-brain dominance, with this pattern being consistent across both genders though slightly higher among female students. This dominance pattern, typically associated with logical and analytical thinking, was expected to correlate with better mathematical understanding. However, the findings challenge this assumption.

Concerning the relationship between brain dominance and mathematical understanding, the results demonstrate that left-brain dominance does not guarantee deep conceptual understanding. High error rates were observed across left-brained (80% in males, 73% in females) and right-brained students, indicating that cognitive predispositions alone are insufficient for mathematical mastery. This finding suggests that hemispheric dominance, while influential, is not the primary determinant of mathematical success.

Regarding pseudo-understanding manifestations, the study identified this phenomenon in both conceptual and analytical dimensions. Nineteen students demonstrated pseudo-understanding in the conceptual dimension, predominantly among females with both left and right brain dominance. In the analytical dimension, cases were most prevalent among left-brained female students. This pattern suggests that strong logical-analytical skills can mask conceptual misunderstandings, allowing students to develop seemingly correct problem-solving procedures without genuine comprehension.

Regarding gender differences, female students showed higher susceptibility to pseudo-understanding across both dimensions despite their predominant left-brain dominance. This finding highlights the complex interplay between cognitive styles, gender, and mathematical understanding, suggesting that factors beyond hemispheric dominance influence learning outcomes.

These findings collectively answer the central research question by demonstrating that while brain hemisphere dominance influences learning patterns, it does not determine mathematical understanding quality. Pseudo-understanding is a significant challenge that transcends cognitive predispositions, requiring educational approaches to prioritize conceptual depth over procedural fluency. The study contributes to the growing body of literature emphasizing the need for holistic mathematics education that addresses cognitive and metacognitive aspects of learning, ultimately supporting more effective instructional practices that can identify and address pseudo-understanding in mathematics education.

Disclosure statement

The author declares that there is no potential conflict of interest in this article's research, authorship, and/or publication. This research was conducted independently without any financial, personal, or other relationship interests that could affect the results or interpretation of the reported research.

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