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Analysis of Students' Misconceptions in The Exponential Numbers Material in Terms of Concept Understanding Through Four-Tier Diagnostic Tests Based on Gender

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ABSTRACT

Misconceptions are a fundamental problem in mathematics learning because they can hinder students' understanding of more advanced concepts, particularly in exponentiation. This study aims to describe students' misconceptions in exponentiation material in terms of conceptual understanding using a four-tier diagnostic test stratified by gender. This research employed a descriptive, qualitative approach. The research subjects were eighth-grade students of SMP Negeri 31 Tanjung Jabung Timur in the odd semester of the 2025/2026 academic year, selected using purposive sampling, namely, students identified as experiencing misconceptions. The research instruments consisted of a four-tier diagnostic test equipped with the Certainty of Response Index (CRI) and semi-structured interview guidelines. Data were analysed by classifying students' responses into the following categories: conceptual understanding, partial understanding, false understanding (positive and negative), misconceptions, and lack of conceptual understanding. The results showed that 23 of 38 students experienced misconceptions, with a higher proportion among male students than among female students. The identified misconceptions included generalisation, notation, overspecialization, and mathematical language. These findings indicate that gender differences influence students' tendencies to experience misconceptions in exponentiation material. Therefore, the four-tier diagnostic test is effective for identifying misconceptions in depth and can serve as a basis for teachers to design more appropriate instructional strategies to reduce students' misconceptions.

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1. INTRODUCTION

Understanding mathematical concepts is an important aspect of the learning process, as it provides students with a basis for solving various mathematical problems logically and systematically. One topic that often poses difficulty for junior high school students is

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exponents. The percentage of students who made mistakes in the written test on exponents was as follows: 1) conceptual errors (43.67%), 2) procedural errors (48.27%), 3) errors in calculation operations (8.04%) [1]. The high percentage of conceptual and procedural errors in exponents indicates that many students still have misconceptions in understanding exponents. The contributing factors are classified into internal factors (such as misconceptions and a tendency to memorise without understanding), external factors (such as a non-contextual approach to learning and a lack of visual aids), and differences in students' academic ability [2].

Misconceptions are incorrect understandings of a concept, which students are often unaware of. This lack of awareness can lead to misconceptions that carry over into subsequent material, hindering the overall learning process. Misconceptions themselves arise from incorrect understandings of a concept. The cognitive structure scheme that has been formed into an understanding will continue to be used in the formation of further cognitive structure schemes [3]. Various diagnostic tests can be used to analyse conceptual errors in students' answers, including the four-tier diagnostic test [4][5]. Its advantage is that it not only identifies correct or incorrect answers but also provides information about students' understanding and confidence in the concept of exponents.

The four-tier diagnostic test is a test instrument consisting of four levels. The first level consists of multiple-choice questions with four distractors and one correct answer that students must choose. The second level assesses students' confidence in their chosen answers. The third level measures students' reasons for answering questions, with four reasons provided to choose from. The fourth level measures students' confidence in choosing their reasons [6]. The second and fourth levels measure the student's confidence level using the Certainty of Response Index (CRI) technique [7]. CRI is a technique for assessing respondents' confidence or certainty in answering each question, enabling the accurate measurement of students' levels of understanding [8].

In addition, gender factors can also influence how male and female students understand mathematical concepts. Clear differences between male and female students are evident in their understanding [9]. Research by Rahmawati, Nurcahyono, and Balkist (2024) used tests and non-tests on flat-sided shapes. The results showed that gender influenced students' mathematical misconceptions in flat-sided shapes, with male students experiencing more misconceptions than female students [10]. Male students experienced misconceptions in the conceptual, translation, calculation, and strategy domains [11]. Meanwhile, female students experienced misconceptions across signs, calculations, and concepts.

This study will use an in-depth four-tier diagnostic test to measure students' answers, reasoning, confidence levels, and self-assurance. This approach has not yet been widely applied, particularly to exponent material. The main focus of this study is exponents because this topic often leads to misconceptions, such as errors in understanding the rules for zero exponents, negative exponents, exponent operations with different bases or exponents, and converting fractional exponents to root forms. In addition, research on misconceptions in this material has not been widely reviewed from a gender perspective, even though there may be differences in the way male and female students think and understand concepts.

2. METHOD

The research conducted in this study used qualitative methods. The approach in this study used a descriptive method to present an object or phenomenon in narrative form. The data collected consisted of students' responses to the four-tier diagnostic test and their oral statements from interviews. The data sources in this study were responses to the four-tier diagnostic test on exponents and interview guidelines used to gain in-depth knowledge of students' misconceptions about exponents. The technique used to select the subjects or research samples was purposive sampling. The subjects in this study were male and female students who had misconceptions, comprising 38 students in classes VIIIA and VIIIB at SMPN 31 Tanjung Jabung Timur, as shown in the table of criteria for grouping student conceptions based on the four-tier diagnostic test supplemented with CRI.

The credibility of the research data was tested through triangulation, which involves verifying data from multiple sources using different methods and at different times. There are three types of triangulation: source triangulation, technique triangulation, and time triangulation [12] [13]. After collecting the data, the researchers transcribed all of the recordings. The recordings were then reduced, with items unrelated to the research objectives removed from the reduced data transcripts; the resulting transcripts were tested for credibility and analysed to conclude.

3. RESULTS AND DISCUSSION

3.1. Results

Based on the results of the four-tier diagnostic test conducted on all eighth-grade students at SMP Negeri 31 Tanjung Jabung Timur, it was found that many students still had misconceptions, compared to those who did not. The percentage of misconceptions among male students was 37%, while among female students it was only 24%, lower than among male students. Meanwhile, 31% of female students and 8% of male students did not experience misconceptions. These findings indicate that, in general, students' understanding of exponents remains relatively low, as evidenced by high levels of misconceptions, especially among male students.

The high percentage of misconceptions is in line with Suparno's (2013) opinion that misconceptions are inaccurate understandings of concepts and tend to persist because they have been built into students' cognitive structures [14]. Students who experience misconceptions not only answer incorrectly, but also have strong beliefs about their answers, making it difficult to correct conceptual errors if they are not detected accurately. This condition also supports the constructivist view put forward by Driver (1989), that students' knowledge is constructed based on their preconceptions and initial experiences; if these preconceptions are not in line with scientific concepts, they can develop into alternative understandings or misconceptions [15].

The difference in the percentage of misconceptions by gender shows variations in the characteristics in understanding and interpreting mathematical concepts. Amir (2013) explains that male students tend to be more courageous in making decisions and show a high level of confidence in their answers, even though their understanding of the concept is not entirely correct [16]. Conversely, female students tend to be more cautious and reflective in answering questions, so the percentage of female students who do not experience misconceptions is higher than that of male students. This indicates that the level of confidence in answers also influences the emergence of misconceptions, as identified through the four-tier diagnostic test.

In addition, the findings of students who answered incorrectly with a high level of confidence reinforce the Certainty of Response Index (CRI) theory proposed by Hasan et al. (1999), that incorrect answers with high confidence are a strong indicator of misconceptions, while incorrect answers with low confidence indicate a lack of understanding of the concept [17]. Thus, the use of the four-tier diagnostic test in this study proved effective in distinguishing students who experienced misconceptions, understood the concept, had a false understanding (positive), had a false understanding (negative), partially understood the concept, and did not understand the concept.

Overall, misconceptions are a complex phenomenon influenced by students' cognitive structures, their level of confidence in their answers, and gender-based learning characteristics. Therefore, these findings emphasise the importance of using diagnostic instruments that can reveal students' conceptual understanding in depth.

3.2. Discussion

Analysis of Misconceptions in Female Subjects (SMP)

The dominant misconceptions among SMP subjects concern language and specialisation, indicating that their understanding remains partial and not yet conceptually integrated. This finding is in line with the research by Arda et al. (2023), which confirms that the four-tier instrument can identify misconceptions more accurately because it not only assesses answers but also reasons and levels of confidence, so that latent misconceptions can be revealed through a combination of incorrect answers and high confidence [18].

Language misconceptions among junior high school students were demonstrated by their difficulty in understanding the mathematical terms used in the questions, such as the meanings of ‘exponent’, ‘base’, and ‘simplest form’. Errors in understanding these terms lead subjects to misinterpret the questions, resulting in the selection of solution strategies that are not appropriate for the problems. According to Suparno (2013), differences in meaning between everyday and mathematical language are often a source of misconceptions, as students build their understanding on incorrect linguistic associations [14].

In addition, junior high school subjects demonstrated misconceptions about specialisation, as evidenced by their inability to apply the concept of exponents in various situations. Subjects tended to be able to solve routine problems similar to the examples, but experienced difficulties when faced with variations in problems or different contexts. This condition indicates that the subjects' understanding of the concept remained limited to certain cases. This is in line with Sarlina's (2015) opinion, which states that understanding mathematical concepts should enable students to apply concepts in various situations, not just in specific examples [19]. Research by Nurkamilah & Afriansyah (2021) and Salsabila et al. (2024) also found that students often have difficulty transferring the concept of exponents to fractional exponents, root forms, and scientific notation, leading to misconceptions about specialisation [20], [21].

Misconceptions about notation in secondary school subjects were also found, although not predominantly. The errors that occurred were related to the subject's inaccuracy in interpreting symbols and exponential notation, such as confusion in distinguishing between the role of the base and the exponent. According to Suparno (2013), misconceptions about notation can arise from incomplete reasoning, in which students manipulate symbols without understanding their conceptual meaning [14]. In line with this, research by Arda et al. (2023) shows that misconceptions about notation are often undetected in regular tests because the answers appear correct, but in the four-tier test, it becomes apparent that the reasoning and beliefs are not in accordance with the concept [18].

Meanwhile, misconceptions in generalisation among secondary school subjects are relatively lower than those in other types of misconceptions. However, in several questions, subjects still appear to generalise the rules of exponents without understanding the context of their application. This shows that students' initial preconceptions still influence how they understand concepts, as explained in constructivist theory, which holds that students' knowledge is built from initial experiences that are not always in line with scientific concepts (Driver, 1989) [15]. This finding is in line with the research by Salsabila et al. (2024), which states that inappropriate generalisation is a dominant source of misconceptions in exponents, especially when students assume that exponent rules can be used in all forms of operations [21].

Analysis of Male Misconceptions Subjects (SML)

The results of the four-tier diagnostic test and interview analysis show that SML subjects experience misconceptions in all types classified by Nurkamilah & Afriansyah (2021) [20]. However, the most dominant misconceptions among SML subjects were generalisation and notation misconceptions, indicating a tendency to use rules and symbols mechanically without adequate conceptual understanding. This is in line with the findings of Rahmawati et al. (2024), which show that male students tend to have higher confidence in the answers they give, thereby potentially perpetuating misconceptions, especially in the context of symbolic and abstract mathematical concepts [10].

Misconceptions about generalisation in SML subjects are evident when students generalise the properties of exponents across various types of questions without considering context. SML subjects tend to memorise rules and apply them directly, even when the question conditions do not meet the requirements for their use. According to Suparno (2013), this misconception can arise from preconceptions that are not properly reconstructed during the learning process [14], [22]. This is in line with the constructivist view that students actively construct knowledge based on previous experiences, which, if incorrect, can result in persistent misconceptions [15]. This finding is reinforced by Salsabila et al. (2024), who emphasise that errors in generalising exponents often occur when students do not understand the limitations of the concept, such as when exponents are added or subtracted [21].

In addition, SML subjects demonstrated misconceptions about notation, characterised by errors in understanding symbols and exponential notation. Students often interpreted exponents as the result of ordinary arithmetic operations, thereby failing to understand the conceptual relationship between the base and the exponent. According to

Suparno (2013), misconceptions about notation are related to associative thinking, in which students associate mathematical symbols with experiences that are not appropriate [14]. These findings are in line with Arda et al. (2023), who stated that misconceptions about notation tend to be accompanied by a high level of confidence, because students feel that symbols can be manipulated according to rules that are considered correct [18].

Misconceptions about specialisation in SML subjects are evident when students are only able to solve problems in certain forms but fail to apply the concept of exponents in different situations. This shows that students' understanding remains narrow, limited to examples they have learned. Based on the understanding criteria according to Renner et al. (1990), this condition falls into the category of partial understanding with specific misconceptions [23]. A similar condition was also found by Nurkamilah & Afriansyah (2021), namely that students experienced misconceptions when exponent problems were presented in the form of roots or fractional exponents [20], [24].

Meanwhile, language misconceptions in SML subjects are relatively rare compared to other types of misconceptions. However, some students still have difficulty understanding certain mathematical terms, which leads to errors in interpreting questions [25]. This shows that mathematical language still plays a role in the formation of conceptual understanding, even though it is not a dominant factor in SML subjects.

Based on this analysis, it can be concluded that misconceptions in junior high school and senior high school subjects differ in their characteristics. SMP subjects tend to experience misconceptions in language and concept application, while SML subjects predominantly experience misconceptions in rule generalisation and symbolic notation. This difference indicates that misconceptions are influenced not only by the material but also by the way students construct knowledge within their cognitive structures.

This shows that students' misconceptions about exponents are not solely due to a lack of practice or accuracy, but are more closely related to incorrect initial knowledge construction, incomplete conceptual understanding, and limitations in interpreting mathematical symbols and language. Thus, these findings emphasise the importance of learning that fosters conceptual understanding, reinforces symbolic meaning, and facilitates concept transfer, enabling students to reconstruct their knowledge in a more profound and meaningful way.

4. CONCLUSION

Based on the results of the four-tier diagnostic test on exponents, misconceptions remained prevalent among students. Misconceptions were characterised by incorrect answers and incorrect reasoning accompanied by a high level of confidence, indicating that students had an incorrect understanding of the concept but believed it to be correct. Overall, 23 of 38 students had misconceptions, while 15 did not. In general, students' misconceptions about exponents predominantly appeared in: 1) the application of exponent properties that were not contextually appropriate, 2) errors in interpreting notation (negative signs and parentheses), and 3) errors in mixed operations involving exponents.

From a gender perspective, the results show that misconceptions occur in both male and female students, but the proportions differ. Misconceptions were found in 14 male students (37%), while in female students, they were found in 9 students (24%). These findings indicate that misconceptions in exponent material are more prevalent among male students than female students.

This difference indicates that there are variations in conceptual tendencies by gender, especially in students' confidence in their answers and the reasons they choose in the four-tier test. Thus, gender can be considered one factor related to students' tendency to develop misconceptions in exponent learning.

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