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Analysis of Students' Misconceptions about the Earth and Its Changes Using a Three-Tier Test

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ABSTRACT

This study aims to analyze elementary school students' misconceptions about the Earth and its changes using a three-tier diagnostic instrument. An accurate understanding of Earth's phenomena is very important for students to build a foundation of scientific thinking from an early age. However, in reality, many students hold incorrect initial conceptions that continue over time, leading to misconceptions that are difficult to detect through conventional tests. For this reason, this study employed a survey method with a mixed quantitative and qualitative approach to identify the patterns and depth of students' misconceptions. The research participants consisted of 38 sixth-grade students from one elementary school in Sukabumi Regency. Data were collected using 10 items of a three-tier diagnostic instrument that included answer choices, levels of confidence, and students' conceptual reasoning. The analysis indicated that students experienced various misconceptions across several sub-concepts of Earth and its changes, with an average percentage of misconceptions reaching 56%. These findings indicate that most students have not yet developed a comprehensive scientific understanding of these natural phenomena. Therefore, it can be concluded that the three-tier diagnostic instrument is effective for identifying and analyzing students' misconceptions and can serve as an important reference for teachers in designing Natural Science learning strategies that are more meaningful and oriented toward conceptual understanding.

Keywords: misconceptions, three-tier diagnostic test, Earth and its changes

INTRODUCTION

Natural Science (IPA) is a field that plays an important role in equipping students with scientific thinking skills and conceptual knowledge needed to understand natural phenomena and solve everyday problems [1]. Comprehensively, by capturing the essence of Natural Science through a scientific approach, students are expected to apply their knowledge to improve the quality of life and contribute to a better society [2][3]. Nevertheless, research shows that many elementary school students bring initial conceptions that differ from formal scientific concepts, which are often continued and are difficult to change [4][5]. These differences in conceptions, commonly referred to as misconceptions, can hinder cumulative learning in the Natural Science domain because scientific concepts are interrelated [6].

Topics related to the Earth and its changes, such as the structure of the Earth's layers, surface formation processes, plate dynamics, the water cycle, and erosion, frequently appear in the literature as sources of misconceptions among elementary school students because these concepts are often abstract and closely related to everyday experiences that can shape incorrect intuitive interpretations [7][8]. If misconceptions about Earth-related topics are not identified and corrected early, evidence shows they tend to continue and affect understanding of more advanced concepts at subsequent educational levels [9].

The next problem is the difficulty teachers face in accurately detecting misconceptions using conventional assessment tools [10]. Most elementary school teachers still use one-tier multiple-choice tests, which only assess whether answers are correct or incorrect, without allowing exploration of students' reasoning or their level of confidence in those answers [11]. In fact, two students who select the correct answer may not have the same level of understanding: one may be accurate by guessing, while the other is correct because of conceptual understanding. Therefore, detecting misconceptions requires diagnostic instruments that provide richer information and reveal the structure of students' conceptual thinking [12].

The detection of misconceptions requires diagnostic instruments that are richer in information than conventional one-tier multiple choice tests,

because simple instruments often fail to reveal the reasoning behind students' answers or their level of confidence [13]. Tiered instruments such as the three-tier format (answer, reasoning, confidence) and the four-tier format (answer, reasoning, confidence, and metacognitive or probability options) have been widely used to identify patterns of misconceptions and to distinguish between lack of knowledge, guessing, and confident misconceptions [14][15][16][17]. Nevertheless, studies that specifically develop and apply these instruments to analyze misconceptions about the Earth and its changes at the elementary school level remain very limited, particularly in the context of Indonesian education. In fact, Indonesia's geographical and cultural conditions, with geological phenomena such as earthquakes, volcanoes, and erosion that are directly encountered in everyday life, provide a unique context that can affect the way students construct their scientific concepts [18]

In this context, the authors used a three-tier test to analyze elementary school students' misconceptions on the topic of the Earth and its changes in a contextual manner within the local environment. Recent studies indicate that three-tier tests are effective at revealing types of misconceptions across various Natural Science topics at both secondary and elementary school levels, while research on the development and validation of such instruments for the elementary school context has increased in recent years [19]. However, the literature also indicates the presence of a gap, namely that studies which more extensively compare the effectiveness of tiered instruments and apply them specifically to the topic of the Earth and its changes in the elementary school context remain relatively limited, thus additional empirical analysis is required to provide local contextual evidence and practical recommendations for teachers [20].

This study not only identifies students' answers but also traces the reasoning and levels of confidence underlying those answers to distinguish between misconceptions, lack of knowledge, and guessing. This approach is expected to provide a more holistic picture of the patterns of misconceptions that occur, as well as to enrich empirical evidence regarding the effectiveness of the three-tier diagnostic test at the elementary level [21]. In addition, the results of this study can provide practical contributions to teachers in designing targeted learning interventions and concept remediation, aligned with the profiles of misconceptions identified.

Based on these needs, this study aimed to analyze elementary school students' misconceptions about the Earth and its changes using a three-tier diagnostic instrument, to identify not only students' answers but also the reasoning and confidence underlying those answers [22]. It is expected that the findings of this study will provide empirical contributions to the practice of diagnosing misconceptions at the elementary school level and serve as a reference for teachers and researchers in designing more effective remediation for Natural Science learning [23].

RESEARCH METHODS

This study used a descriptive survey method to analyze elementary school students' misconceptions about the Earth and its changes, using a three-tier diagnostic test. The survey approach was selected because it allows researchers to obtain an overall picture of students' levels of understanding and misconceptions regarding scientific concepts in the real context of learning in elementary schools [24]. The flow of the research design is presented in Figure 1.

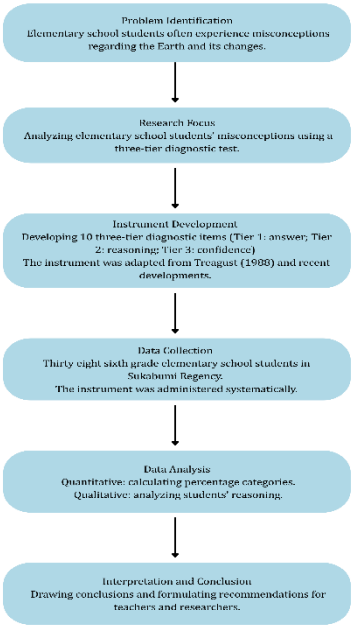

Figure 1. The research flow design
Personal documentation

The population in this study consisted of all sixth-grade students at one public elementary school in Sukabumi Regency during the even semester of the 2024/2025 academic year. The research sample was selected using a purposive sampling technique, given that sixth-grade students had already received learning materials on Earth and its changes in the elementary school Natural Science curriculum. The participants were 38 students, including 20 males and 18 females. The sample size was selected based on the ideal class size for descriptive research at the elementary school level [25].

The data were analyzed quantitatively and qualitatively to provide an overview of students' conceptual understanding based on the diagnostic test results. Quantitative data were obtained from the results of the three-tier diagnostic test, which included students' answers to each item, their levels of confidence, and the reasoning provided. These data were used to calculate the percentage of students in each conceptual category (understanding the concept, not understanding the concept, misconception, and error). Qualitative data were derived from the analysis

of students' conceptual reasoning and patterns of incorrect answers that indicated specific forms of misconceptions. These data helped explain the factors underlying misconceptions and provided a deeper description of students' conceptual understanding [26].

The research instrument was adapted from the three-tier diagnostic test model that has been widely used in studies of Natural Science misconceptions. The instrument was designed as a tiered multiple-choice test with the following structure: the first tier consisted of conceptual answer options, the second tier consisted of reasoning that supported the answer selected in the first tier, and the third tier consisted of students' levels of confidence in the chosen answer, adapted from the model developed by Subramaniam [18]. Accordingly, this instrument can distinguish students who understand the concept, those who do not, and those who experience misconceptions.

The analysis of students' levels of conception was conducted based on the patterns of answer combinations at each tier. The categories of students' conceptions are presented in Table 1. Adapted from F. Nurzakiah Fuadi et al. [27].

Table 1. Categories of Students' Conceptions Based on Three-Tier Test Answer Patterns

Category	Tier 1 (Conceptual Answer)	Tier 2 (Reasoning)	Tier 3 (Confidence)
Understanding the Concept (UC)	Correct	Correct	Confident
Not Understanding the Concept (NUC)	Correct	Correct	Not confident
	Correct	Incorrect	Not confident
	Incorrect	Correct	Not confident
	Incorrect	Incorrect	Not confident
Misconception (M)	Correct	Incorrect	Confident
	Incorrect	Incorrect	Confident
Error (E)	Incorrect	Correct	Confident*

*The error category appears when the answer pattern indicates a contradiction between the conceptual choice, the reasoning, and the level of confidence.

RESULTS AND DISCUSSION

The analysis using the three-tier diagnostic instrument on 38 sixth-grade elementary school students in Sukabumi Regency showed that the average percentage of students' misconceptions was 56%. This indicates that the majority of students have understandings that deviate from the scientific concepts of the Earth and its changes. These data were obtained from the implementation of the three-tier diagnostic test developed based on the Basic Competencies of the Merdeka Curriculum Phase C for Classes IV to VI, particularly within the element Earth and Its Changes in the Natural and Social Sciences (IPAS) subject.

The level of concept mastery in Natural Science learning analyzed in this study focused on the Earth and its changes among sixth-grade elementary school students. The basic competencies used included identifying the layers of the Earth where humans live, naming the layers of gases that surround the Earth (the atmosphere), classifying parts of the Earth in the form of water into the hydrosphere layer, distinguishing changes in the Earth's surface caused by natural processes and human activities, and attitudes toward natural features to avoid negative impacts on the Earth. These basic competencies were adapted from the Natural and Social Sciences (IPAS) Learning Outcomes of the Merdeka Curriculum Phase C [28] and served as the basis for developing 10 diagnostic items that reflected conceptual indicators for each subtopic. The results of the analysis of the distribution of students' conceptual-level percentages, grouped into understanding the concept, not understanding the concept, misconception, and error, are presented in Figure 3.

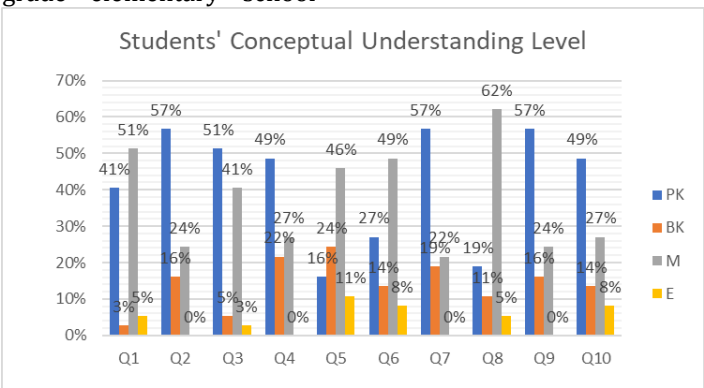

Figure 3. Percentage of Students' Conceptual Level from Each Item

Based on Figure 3, the distribution of students' levels of conceptual understanding across the ten diagnostic instrument items (Q1–Q10) shows that the misconception category (M) dominates most of the items. For example, item 8 shows the highest percentage of misconceptions at 62%, item 6 at 49%, and item 5 at 46%. Meanwhile, the category of understanding the concept (UC) tends to be strong in items such as numbers 2 and 9, each reaching 57%, indicating that, for certain indicators, such as identifying layers of gases or classifying parts of the Earth as water, students show better understanding.

However, the levels of not understanding the concept (NUC) and error (E), although lower, remained consistently high across all items. For example, item 5 showed a lack of understanding of the concept, with a percentage of 24%, while the error category appeared in item 5 at 11% and in item 6 at 8%. The presence of not understanding the concept and errors may be caused by a lack of direct experience, limited visualization, students' reasoning unsupported by scientific facts, or unclear explanations in instructional materials. Previous studies have also found that misconceptions often arise from students' initial incorrect experiences and from teaching methods that do not support conceptual clarification [29][30].

These findings reinforce the view that students do not come to school as blank slates to be filled by instruction; instead, they bring prior knowledge of the Earth and environmental phenomena from their everyday experiences [31]. This prior knowledge shapes conceptions that sometimes deviate from scientific concepts, so even before formal learning begins, students already possess their own frameworks of thinking about the Earth and its changes [32]. Analyzing students' conceptions using a three-tier diagnostic instrument allows teachers to investigate hidden misconceptions and variations in understanding across different conceptual indicators. Thus, the results of this conceptual identification are significant as a foundation for designing instruction that not only corrects misconceptions but also strengthens students' scientific understanding comprehensively [5].

Several contributing factors can explain the dominance of misconceptions in this study. First, students' initial experiences with natural phenomena often give rise to intuitive reasoning that conflicts with scientific logic [33]. For example, students may view earthquakes solely as ground shaking, without realizing that the movement of tectonic plates causes them. Second, the abstract and multiscale nature of geoscience concepts, such as the structure of the Earth's layers, the atmosphere, and the hydrosphere, makes them difficult for students to observe directly and requires a high level of visualization ability [34]. Third, limitations in instructional methods, such as the minimal use of visual media, concrete models, and inquiry-based approaches, also contribute to the reinforcement of conceptual misunderstandings [34].

In addition, conventional assessment instruments that rely solely on one-tier multiple-choice tests cannot reveal the reasoning and levels of confidence underlying students' answers, leading to many hidden misconceptions [19]. The three-tier diagnostic instrument used in this study was shown to be capable of identifying deeper patterns of misconceptions because it considers three aspects: students' answers, reasoning, and levels of confidence [15].

The results of this study are consistent with several previous studies. Studies [9], [8], and [35] also reported the dominance of misconceptions on geoscience topics at the elementary school level. They explained that concepts such as the Earth's layers, the atmosphere, and changes in the Earth's surface are prone to misinterpretation because they are abstract and not directly observable. This study also supports the findings of [36], which indicate that students' misconceptions often continue because teachers' instructional approaches do not explicitly challenge and correct them.

However, this study also found different results for several indicators, in which students showed relatively good understanding, particularly in the subtopics of identifying the layers of the atmosphere and classifying parts of the Earth in the form of water (items 2 and 9). These results differ slightly from previous studies that reported misconceptions occurring evenly across all indicators. Such differences are likely affected by local contextual factors, such as curriculum emphasis, teachers' instructional focus, and tangible environmental experiences.

Overall, although some students have already shown good understanding, the dominance of misconceptions indicates that students have not yet developed a complete scientific conceptual picture across most indicators. Indicators such as explaining the consequences of tectonic plate collisions and identifying the causes of coastal abrasion are the areas with the highest levels of misconceptions. Therefore, teachers need to design learning activities that not only convey definitions but also take into account students' reasoning and confidence, and use concrete visual media and reflective discussions to help students correct their misconceptions [37].

Concepts held by students who experience misconceptions are often referred to as alternative conceptions. The alternative conceptions most frequently selected by students for each question item are presented in Table 2.

Table 2. Student Alternative Concepts

Code	Indicator	Alternative Concept	Alternative Reason
Q1	Identifying the layer of the Earth where humans live	Humans live in the Earth's core layer	Because the Earth's core is considered the center of life
Q2	Naming the layer of gases that surrounds the Earth (atmosphere)	The atmosphere consists only of oxygen	Because oxygen is the gas most needed by humans
Q3	Classifying parts of the Earth in the form of water into the hydrosphere layer	The hydrosphere consists only of seas and rivers	Because groundwater is not visible and is therefore considered not part of the hydrosphere
Q4	Distinguishing changes in the Earth's surface caused by natural processes and human activities	All changes in the Earth's surface are caused by humans	Because human activities are perceived as more dominant than natural events
Q5	Explaining the impact of deforestation on the environment	Deforestation makes the air fresher	Because trees are considered to obstruct air circulation
Q6	Determining appropriate actions during an earthquake	Running out of the house without direction	Because panic is believed to help save oneself more quickly
Q7	Identifying the causes of coastal abrasion	Coastal abrasion occurs due to earthquakes	Because earthquakes are considered the main cause of land changes along coastal areas
Q8	Explaining the consequences of tectonic plate collisions	Plate collisions cause heavy rainfall	Because rainfall is often associated with natural disasters
Q9	Evaluating the best ways to prevent urban flooding	Allowing rivers to become clogged with waste	Because rivers are assumed to be able to carry water even when they are blocked
Q10	Recommending ways to reduce the impacts of earthquakes through earthquake-resistant houses	Earthquake-resistant houses are made of glass or light materials without foundations	Because they are considered more flexible and less likely to collapse

Based on Table 2, most sixth-grade elementary school students show alternative conceptions (misconceptions) rooted in everyday experiences and intuitive reasoning that are not aligned with scientific concepts. For example, in the indicator identifying the layer of the Earth where humans live (Q1), most students believe that humans live in the Earth's core, based on the reasoning that the core is the center of life. In fact, scientifically, humans live on the Earth's crust. This error indicates a mismatch between students' empirical concepts and the actual scientific concepts.

Important findings in this study indicate that students' misconceptions most frequently occur in abstract concepts that cannot be directly observed, such as the Earth's layers, the atmosphere, and tectonic plate collisions. In contrast, for concepts that are more concrete and closely related to everyday life, such as flood mitigation or earthquake-resistant housing, the level of misconceptions tends to be lower. These findings reinforce the view that the level of conceptual abstraction greatly influences students' understanding of science [38].

Several factors may cause this situation. First, students' prior knowledge, formed from everyday experiences, serves as the basis for the emergence of misconceptions [40]. For example, students who frequently see earthquakes on television associate all coastal changes with earthquakes (Q7) or assume that tectonic plate collisions cause heavy rainfall (Q8), since rainfall is often associated with natural disasters. Second, the lack of visual media and concrete experiments in science learning makes it difficult for students to construct accurate mental representations of geosphere phenomena [41]. Third, conventional instructional strategies that focus on memorization without providing space for exploration and conceptual reflection also reinforce misconceptions [3].

Although misconceptions are dominant, there are some indicators that show students' understanding is closer to scientific concepts or less erroneous. For example, indicators related to mitigation (ways to prevent flooding, earthquake-resistant houses) show that some students selected more rational alternatives, even though some misconceptions remain. This indicates that when learning incorporates real-world contexts and mitigation actions, students can develop alternative conceptions closer to scientific concepts. This also shows that instructional design that explicitly corrects conceptual errors and provides opportunities for students to compare alternative conceptions with scientific conceptions can help significantly reduce the prevalence of misconceptions [42].

These findings have important implications for Natural Science learning at the elementary school level, particularly in the context of Earth and its changes. First, teachers need to design inquiry-based learning and use concrete visual representations to help students reconstruct their conceptual understanding [43]. Second, reflective strategies, such as misconception discussions or cognitive conflict-based learning, are

required to help students become aware of the differences between intuitive knowledge and scientific concepts [44]. Third, the results of this study contribute to the development of a three-tier diagnostic assessment as a formative tool for teachers to identify misconceptions from the early stages of learning [12]. Thus, this study not only enriches the empirical literature on misconceptions at the elementary school level but also provides practical guidance for improving the quality of Natural Science learning oriented toward deep conceptual understanding.

CONCLUSION

This study concludes that elementary school students still experience a high prevalence of misconceptions related to the topic of the Earth and its changes, as identified through a three-tier diagnostic test across various indicators, such as the structure of the Earth, the atmosphere, the hydrosphere, as well as natural phenomena, including earthquakes, coastal abrasion, and tectonic plate collisions. The misconceptions that emerge are not only the result of a lack of knowledge, but rather the outcome of incorrect personal logical constructions, such as the belief that humans live in the Earth's core because it is considered the center of life, or that the atmosphere consists only of oxygen because humans need this gas. Thus, the three-tier diagnostic test has proven effective in identifying misconceptions and, at the same time, serves as an important foundation for teachers in designing more targeted learning to instill scientific concepts from an early stage.

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