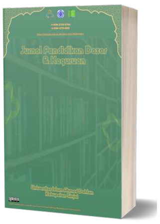

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Analyzing the Characteristics of Elementary School Students' Instrumental Understanding in Solving Mathematics Problems

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Abstract

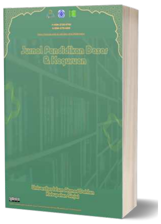
Elementary school students' mathematical understanding is often trapped in the procedural realm without being accompanied by a strong conceptual understanding. This field research aims to analyze and describe in depth the characteristics of instrumental understanding possessed by elementary school students in solving mathematical problems, specifically on the topics of Fractions and the Pythagorean Theorem. This study employed a descriptive qualitative approach. The research subjects consisted of three fifth-grade elementary school students selected using a purposive sampling technique to represent three ability categories based on diagnostic test results: high ability (S-1), moderate ability (S-2), and low ability (S-3). Data were collected through validated diagnostic written tests and task-based clinical interviews. The data analysis followed the stages of data reduction, data display, and conclusion drawing. The results revealed varied characteristics of instrumental understanding: S-1 was able to perform computations correctly but exhibited context rigidity when the visual orientation of the problem was altered; S-2 relied heavily on visual memory of procedural steps, triggering misconceptions due to mechanical memorization; while S-3 experienced procedural mixing due to a lack of conceptual schema. Overall, students understood mathematical rules without knowing the logical reasons behind them (rules without reasons). This study recommends that teachers emphasize a conceptual approach through concrete-pictorial bridges before introducing abstract symbols to students.

Keywords: Instrumental Understanding, Skemp Theory, Fractions, Pythagorean Theorem, Qualitative Research.

1. Introduction

Mathematics is one of the fundamental subjects in the education system that plays an important role in shaping students' logical, analytical, critical, and systematic thinking skills (Aksu & Koruklu, 2015; Cresswell & Speelman, 2020; Maslihah dkk., 2020). Through mathematics learning, students are expected not only to perform calculations, but also to understand concepts, reason relationships between ideas, and apply mathematical knowledge in various real-life contexts (Chance dkk., 2024; Lindström-Sandahl dkk., 2024; Onwubuya & Akputu, 2024). Therefore, understanding becomes a central aspect of mathematics learning, as the quality of students' understanding greatly determines both long-term learning success and the ability to transfer knowledge.

Mathematics learning in elementary schools plays a crucial role as an early foundation in shaping students' logical, critical, and systematic thinking skills (Alvarez-Tinajero dkk., 2026; Mytra dkk., 2021; Payadnya dkk., 2024; Wang dkk., 2025). At this level, students are not only required to be able to calculate, but they must also build a strong mathematical thinking schema to face more complex



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concepts at the next level of education. (Bognar dkk., 2025; Sa'di dkk., 2023; Wardani & Darmayanti, 2024). The success of this process heavily depends on how students construct reasoning and understand abstract mathematical objects introduced from an early age (Nurjannah & Kusnandi, 2021; Saleh dkk., 2017; Sterner dkk., 2020).

In the psychology of mathematics learning, Richard Skemp divides mathematical understanding into two main categories: relational understanding and instrumental understanding (Skemp, 1976). Relational understanding should ideally become the primary goal of learning, where students know what to do while also understanding the logical reasons behind the procedures (knowing what to do and why) (Fitri & Prabawanto, 2021; Herheim, 2023). In contrast, instrumental understanding refers to a condition in which students only know rules or formulas without understanding why those rules can be applied (rules without reasons) (Hill, 1997; Sulasmi dkk., 2020).

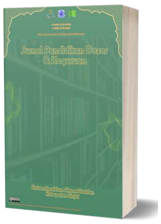
Table 1. Comparison of Characteristics Between Relational and Instrumental Understanding (Skemp, 1976)

Comparative Aspect	Relational Understanding	Instrumental Understanding
Core Ability	Knowing what to do and *why* it is done.	Knowing instant rules/formulas without knowing the reasons for their use.
Schema Characteristics	Interconnected, adaptive, and flexible to changes in context.	Isolated, rigid, and reliant on visual memory of the problem.
Memory Retention	Long-term (due to meaningful learning).	Short-term (prone to tumpang tindih/*cognitive interference*).
Response to Problem Modification	Capable of adjusting problem-solving strategies.	Experiences systematic failure or confusion.

Although relational understanding is considered the ideal learning outcome, the reality in the field shows a contradictory tendency. Many elementary school students remain trapped in instrumental understanding (Hidaiyah dkk., 2023; Utomo, 2020). When faced with mathematical problems, students tend to memorize formulas mechanically and imitate the procedures demonstrated by the teacher without having sensitivity to their conceptual meaning (Asmida dkk., 2018; Richland dkk., 2012). This phenomenon is exacerbated by learning orientations that often place greater emphasis on final results or the speed of solving problems rather than on the depth of students' thinking processes themselves (Braithwaite & Sprague, 2021; Fernandez & Guzon, 2025).

The impact of the dominance of instrumental understanding becomes clearly visible when students solve mathematical problems, particularly problems that require modification or word problems. When the problem stimulus is slightly altered from the examples commonly provided, students with instrumental understanding generally experience systematic failure because they lack cognitive flexibility (Samosir dkk., 2023). They lose direction because the "rules" they have memorized no longer match the structure of the new problem. Therefore, it is important to further explore how the specific characteristics of instrumental understanding emerge when elementary school students engage in mathematical problem solving (Žakelj dkk., 2025).

The strong dependence on instrumental understanding at the elementary school level cannot be regarded merely as a temporary technical error, but rather as an accumulative cognitive barrier. When students become accustomed to treating mathematics as a collection of isolated formula compartments, they fail to construct interconnected conceptual schemas in their minds. In the long term, when they progress to higher levels of education and encounter topics requiring advanced abstraction, such as algebra or formal geometry, these instrumental schemas tend to collapse (Patsiomitou, 2025). As a result, mathematical anxiety and decreased learning motivation emerge because students perceive mathematics as an increasingly illogical subject to memorize. Therefore, mapping the characteristics of



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instrumental understanding from an early stage is no longer merely an effort to evaluate learning outcomes, but rather a preventive urgency to preserve students' mathematical reasoning before these rigid procedural thinking patterns become deeply ingrained.

Several previous studies have extensively discussed students' procedural errors in mathematics; however, studies that specifically isolate and examine the psychological and mechanical characteristics of elementary school students' instrumental understanding through a qualitative field approach still require deeper exploration. This study aims to analyze and describe in depth the characteristics of elementary school students' instrumental understanding in solving mathematical problems. The findings of this study are expected to provide a diagnostic framework for elementary school educators in designing instructional interventions that can shift students' learning orientation from merely memorizing formulas toward meaningful conceptual understanding.

2. Method

This study employed a field research design using a descriptive qualitative approach. This approach was selected because the researcher intended to describe, map, and comprehensively elaborate the natural characteristics of elementary school students' instrumental understanding when solving mathematical problems, without providing any treatment or manipulating the research variables.

The subjects of this study consisted of three fifth-grade elementary school students. To comply with research ethics and maintain privacy, the students' real identities and the name of the school were kept confidential (anonymous) and replaced with pseudonym codes. The subjects were selected using a purposive sampling technique based on the results of a mathematics diagnostic test. From all fifth-grade students at the school, three subjects were chosen to represent three levels of ability, namely:

1. Subject S-1: Student with a high diagnostic test result category.
2. Subject S-2: Student with a medium diagnostic test result category.
3. Subject S-3: Student with a low diagnostic test result category.

The research activities were designed to proceed in a circular and systematic manner, as illustrated in the following stages:

2. 1. Preliminary Observation

The researcher conducted preliminary observations at the elementary school to identify phenomena in the mathematics learning process and indications of students' instrumental understanding when solving problems in the classroom.

2.2. Proposal Preparation

The researcher prepared the research design, which included the background of the problem, a theoretical review of instrumental understanding (Skemp's theory), and the methodology to be implemented in the field.

2.3. Development of Diagnostic Test Instruments and Interview Guidelines

The researcher developed research instruments in the form of diagnostic mathematical problem-solving tests (word problems/concept modification tasks) and prepared task-based clinical interview guidelines to explore the reasoning behind students' procedural answers.

2.4. Expert Validation (Expert Judgment):

The diagnostic test instruments and interview guidelines that had been developed were subsequently reviewed and validated by experts (lecturers/mathematics education specialists) to ensure the feasibility, readability, and validity of the instruments before their implementation.

2.5. Fieldwork (Entering the Research Site):

The researcher entered the research site (school) after obtaining official permission to begin collecting data directly from the primary source.

2.6. Administering the Diagnostic Test:

The researcher administered the validated mathematical diagnostic test instrument to all fifth-grade students in the designated classroom.

2.7. Selecting the Three Research Subjects:

Based on the scores and answer characteristics from the diagnostic test results, the researcher sorted and established three main subjects representing the highest, moderate, and lowest achievement categories.

2.8. Conducting In-Depth Interviews:

The researcher conducted individual clinical interviews with the three selected subjects regarding the tested elementary school mathematics topics. The interviews were focused on exploring the rules without reasons aspect (knowing the formula but not understanding its meaning).

2.9. Analyzing Interview Data:

The researcher examined, organized, and transcribed the students' audio recordings of verbal interviews into text to analyze their thinking patterns.

2. 10. Data Reduction:

The researcher performed data reduction by sorting the raw data from the test results and interview transcripts, discarding irrelevant data, and focusing the analysis on the specific characteristics of the students' instrumental understanding.

2.11. Drawing Conclusions:

The final stage was when the researcher formulated solid conclusions regarding the profile and characteristics of the instrumental understanding of fifth-grade elementary school students based on the triangulation of written test data and field interviews.

3. Result & Discussion

3.1. Result

Data collection was conducted through written diagnostic tests on Fractions and the Pythagorean Theorem, followed by task-based clinical interviews. Based on the data reduction analysis, the profiles of the instrumental understanding characteristics of the three subjects (S-1, S-2, and S-3) are as follows:

a. Subject S-1 (High Ability)

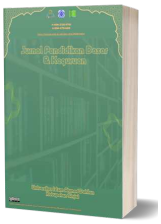
In the written test, S-1 was able to solve all fraction and Pythagorean Theorem problems with correct final results. S-1 deftly used the formula $a^2 + b^2 = c^2$ and performed cross-multiplication operations on the addition of fractions with different denominators. However, the characteristics of instrumental understanding emerged during the clinical interview session:

1. **Fraction Case:** When asked to explain why the denominators must be equalized in the addition of $\frac{1}{2} + \frac{1}{3}$, S-1 answered, "*Because that is the rule from the teacher. If the bottoms are different, they cannot be added directly. We must find the LCM first.*" When asked to illustrate the meaning of those fractions using a pie chart, S-1 was confused about how to connect it with the LCM concept they had used..
2. **Pythagoras Theorem Case:** S-1 memorized the formula to find the hypotenuse. However, when the researcher inverted the position of the right-angled triangle so that the hypotenuse was in a vertical position, S-1 hesitated and still inputted the vertical number as component *a* or *b*, instead of *c* S-1 stated, *"I only memorized that the slanted side is the letter c. If the triangle is rotated, I get confused about which formula to use."*

b. Subject S-2 (Moderate Ability)

S-2 demonstrates a very high dependency on procedural visual memory. If the problem structure is exactly identical to the examples provided by the teacher, S-2 is able to answer it, but fails if there is any minor modification.

1. **Kasus Pecahan:** S-2 committed a typical instrumental understanding error in the fraction division operation (e.g: $\frac{2}{3} \div \frac{1}{4}$). S-2 recalled the "invert and multiply" procedure, changing it to $\frac{2}{3} \times \frac{4}{1}$, but



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when asked why the second fraction had to be inverted, S-2 answered, *"I don't know why it is inverted, but my teacher said if it isn't inverted, the answer will be wrong."* S-2 knows the rules of the game but is blind to the logical reasons behind them.

2. **Pythagoras Theorem Case:** S-2 S-2 wrote the formula correctly but made a fatal error in the squaring computation (e.g: 6^2 writing 12, instead of 36). S-2 instrumentally memorized the format of the exponent symbol (x^2) as a multiplier of the number 2, rather than as the repeated multiplication of the number itself.

c. Subject S-3 (Low Ability)

S-3 experiences cognitive overload due to attempting to memorize too many formulas without a clear schematic structure. Consequently, procedural mixing occurs.

1. **Fraction Case:** In solving $\frac{1}{2}+\frac{2}{3}$, S-3 directly added the numerators together and the denominators together, resulting in the answer $\frac{3}{5}$. When interviewed, S-3 reasoned, *"In fraction multiplication, we just multiply straight across, so I thought for addition we just add straight across too to make it faster*." S-3 failed to differentiate between the procedures for fraction addition and multiplication.
2. **Pythagorean Theorem Case:** S-3 S-3 was unable to recall the Pythagorean formula in its entirety. S-3 only wrote down the numbers given in the problem and added them linearly without squaring them first. S-3 stated, *"I remember there was addition involved, but I forgot the formula that uses those exponents."*

2. Discussion

The field findings from the three subjects reinforce Richard Skemp's theory regarding the manifestation of instrumental understanding (*rules without reasons*) in elementary school-aged children. Several key characteristics of instrumental understanding were successfully identified from the subjects' mathematical problem-solving results:

a. Rules Dependency

Students perceive mathematics not as a science of logical reasoning, but rather as a set of "laws" handed down by the teacher or textbooks. This is clearly evident in S-1 and S-2, who were capable of performing fraction computations (such as equalizing denominators or inverting fractions in division) yet attributed the absolute validity of the procedure to "the teacher's instructions." Consequently, their knowledge is artificial and fragile

b. Context Rigidity (Fragility of Schema Against Contextual Changes)

A defining characteristic of instrumental understanding is the inability to adapt when the visual presentation of a problem is altered. The phenomenon observed in S-1, who became confused trying to identify the hypotenuse when the right-angled triangle was rotated, proves that students do not comprehend the essence of the relationships between the sides of a right triangle. Instead, they merely memorize visual geometric positions (the base, the vertical side, and the slanted side).

c. Emergence of Misconceptions Due to Rote Memorization

In subjects S-2 and S-3, instrumental understanding led to fatal conceptual errors (such as calculating $6^2 = 12$ and mixing up the procedures for fraction addition and multiplication). When students are taught mathematics solely through step-by-step memorization (procedural), their brains store this information in short-term memory. As that memory fades, the memorized procedures overlap (cognitive interference), generating erroneous, student-made formulas.

d. Implications for Learning and Instruction

The topics of fractions and the Pythagorean Theorem require a transition from the concrete to the abstract. The predominant instrumental understanding observed in all three subjects indicates that elementary school mathematics instruction frequently bypasses the concrete-pictorial stage and directly forces students into the symbolic stage (instant formulas). To shift this understanding toward relational understanding, teachers must emphasize conceptual approaches—such as using manipulative media for

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fraction concepts and visual proofs (area of squares) for the Pythagorean Theorem—ensuring that students know both what to do and why it must be done (*knowing what to do and why*).

4. Conclusion

Based on the field research results and discussion, it can be concluded that the characteristics of instrumental understanding among elementary school students in solving mathematical problems regarding Fractions and the Pythagorean Theorem vary according to their ability levels, yet share a similar pattern of cognitive failure:

High-Category Students (S-1) exhibit characteristics of instrumental understanding in the form of rules dependency and context rigidity. The student is capable of completing computations correctly but fails to explain the logical foundation of the procedure and becomes confused when the visual orientation of the problem is modified.

Moderate-Category Students (S-2) demonstrate a strong dependency on the visual memory of procedural steps without understanding the meaning of the symbols. This triggers fatal misconceptions (such as interpreting the squaring operation as multiplying by two) due to mechanical symbol memorization.

Low-Category Students (S-3) experience cognitive interference and procedural mixing. The absence of a conceptual schema causes the student to attempt to memorize all formulas randomly; consequently, as short-term memory fades, these formulas overlap and are applied to the wrong problem contexts.

In general, the characteristics of instrumental understanding at the elementary school level are marked by the students' inability to connect procedural aspects (knowing what to do) with conceptual aspects (knowing why). Teachers are expected to move away from instant "shortcut/practical formula" methods and begin emphasizing the use of concrete-pictorial bridges before introducing abstract mathematical symbols.

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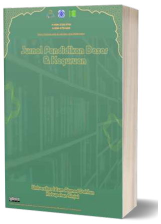

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