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ANALYSIS OF MATHEMATICAL CONCEPTUAL UNDERSTANDING IN SOLVING NUMBER PATTERN PROBLEMS AMONG EIGHTH-GRADE JUNIOR HIGH SCHOOL STUDENTS

Andi Mulawakkan Firdaus[1*], Siti Rahaimah Binti Ali[2]

[1]Mathematics Education Department, Universitas Muhammadiyah Makassar, Makassar, Indonesia

[2]Department of Mathematics Education, Universiti Pendidikan Sultan Idris, Malaysia.

** Korespondensi Penulis. E-mail: andi.mulawakkan@unismuh.ac.id*

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ABSTRACT

Conceptual understanding is the foundation for mastering higher-order mathematical competencies, yet student achievement in number patterns remains suboptimal. This study aims to describe the mathematical conceptual understanding of eighth-grade students at SMP Negeri 5 Bulukumba in solving number-pattern problems, based on seven indicators of conceptual understanding. A descriptive design with a mixed-methods sequential explanatory model was employed. The research subjects were 23 students of class VIII B, selected through purposive intact-class sampling; six of them, consisting of two students in the very high category, two in the moderate category, and two in the very low category, were purposively selected for task-based interviews. Data were collected through a three-item essay test and one interview task, then analysed using descriptive statistics and the interactive analysis model of Miles, Huberman, and Saldana, with data validity examined through technique triangulation. The results show an average error rate of 32.56% across the seven indicators. The lowest error rate occurred on the indicator of restating a concept (19.5%), whereas the highest error rates occurred on the indicators of selecting particular procedures or operations and of applying concepts in problem solving, each at 39.1%. Nevertheless, the differences between indicators correspond to only one or two students, so the ordering of difficulty must be interpreted cautiously. Classical mastery reached only 43.48%, far below the minimum criterion of 80%. Interview data indicate that low-achieving students tend to manipulate only the numbers visible in the problem without selecting an appropriate procedure, and that indicator mastery is not strictly hierarchical.

INTRODUCTION

Mathematics occupies an essential position in the primary and secondary education curricula because it equips students with logical, systematic, and critical reasoning skills. One of the main goals of school mathematics instruction is for students to understand mathematical concepts, explain interrelationships between concepts, and apply concepts or algorithms flexibly, accurately, efficiently, and appropriately in problem solving (Depdiknas, 2006). This goal places conceptual understanding not merely as a supplement, but as the foundation for all other mathematical abilities.

A literature review by Sengkey et al. (2023) indicates that mathematical conceptual understanding is defined as the ability to construct the meaning of a mathematical object so that one can restate, classify, exemplify, represent, and apply the concept to new situations. Sape, H., & Muh. Ridwan (2024), conceptual understanding cannot be achieved through memorising solution steps. Yanti et al. (2022), referring to Kilpatrick's framework, emphasize that conceptual understanding and procedural fluency are two mutually supportive yet non-identical strands of proficiency; thus, students can calculate fluently without understanding the meaning of the operations. Sidik and Sudiana (2023), who analyzed the mathematical understanding of eighth-grade students using the Pirie-Kieren theory, also found that most students stop at the initial layers of understanding and rarely reach the formalisation layer. The hierarchical nature of mathematics causes weaknesses in understanding one topic to potentially propagate to subsequent topics.

Number patterns represent an eighth-grade topic that demands conceptual understanding while serving as a prerequisite for sequences and series in senior high school. Wulandari and Machromah (2024) demonstrated that this material is widely used to measure higher-order reasoning because it requires students to identify pattern-generating rules rather than merely applying formulas. The core task in this material is generalisation, deriving general rules from specific cases, and it is precisely in this process that student errors most frequently occur (Setiawan, 2020a). This topic also bears strong connections to everyday life, such as seating arrangements, library collection numbering, and numerical reasoning items in academic potential tests (Sudirman, 2023). Weaknesses in conceptual understanding of number patterns do not stop at a single topic: Septiahani et al. (2020) found that senior high school students' errors in sequences and series largely stem from unestablished pattern concepts from previous grade levels.

Initial observations and interviews with mathematics teachers at SMP Negeri 5 Bulukumba revealed symptoms aligned with these issues. Students tend to solve problems by following the sequence of steps demonstrated by the teacher without understanding the rationale behind each step. Consequently, when problems are modified, even while keeping the core problem intact, some students experience difficulty. Students' abilities to define concepts, discover concept properties, and provide examples and non-examples remain limited.

Recent studies have highlighted similar issues in number patterns. Utomo et al. (2022) found that over 60% of eighth-grade students committed errors in determining square number patterns presented as sequences or visual diagrams, with error proportions rising on items requiring the formulation of the n-th term. Setiawan (2020a) categorized linear pattern generalisation errors into two forms: overgeneralisation stemming from selective processing of partial data, and overspecialisation stemming from restricting the meaning of terms. Devi and Amir (2021) added an important dimension: in pattern generalisation tasks, low- and moderate-ability students tend to commit conceptual errors, whereas high-ability students tend to make only procedural errors. Inastuti et al. (2021) reported that problem-solving ability in number patterns varies by learning style, with the primary obstacle occurring during the plan-formulation stage.

Across topics other than number patterns, conceptual mapping has been conducted by Yanala et al. (2021) on integer operations, Rahmawati and Roesdiana (2022) on algebraic function derivatives, and Oktapiana et al. (2025) on whole number arithmetic operations. Mayasari and Habeahan (2021) observed a dissociation between the ability to explain concepts and the ability to use formulas: some students can explain concepts but fail to operate them, whereas others can operate formulas but cannot explain their meaning. From an error analysis perspective, Astrianingsih et al. (2023), Sari and Pujiastuti (2022), and Chairani and Darmawan (2025) demonstrated that student errors in number topics are multi-layered and cannot be reduced merely to computational mistakes. Non-cognitive factors also play a role, as reported by Nurhandita et al. (2021) regarding the link between self-confidence and conceptual understanding, and Miatun and Ulfah (2023) regarding the role of mathematics anxiety.

The study closest to this research is Pratiwi and Isnaningrum (2021), who analyzed the mathematical conceptual understanding of eighth-grade students on number patterns and obtained an average score of 62.4 (moderate category). However, that study stopped at establishing aggregate understanding levels and involved only three interview subjects as category representatives, without mapping mastery across each indicator separately. Other studies generally stop at classifying error types or mapping conceptual understanding in topics other than number patterns. A mapping that systematically places number patterns across all seven conceptual understanding indicators while exploring indicator mastery profiles across three contrasting ability levels via task-based interviews remains scarce. This gap is what the present study addresses.

Based on the above background, this study was formulated to answer two questions: First, what is the percentage of errors made by eighth-grade students at SMP Negeri 5 Bulukumba across each indicator of conceptual understanding when solving number-pattern problems? Second, what are the indicator mastery profiles of conceptual understanding among students in the very high, moderate, and very low categories?.

METHOD

Research Design

This study employed a descriptive research design with a mixed-methods sequential explanatory model (Creswell & Plano Clark, 2018). Quantitative data were collected and analyzed first to obtain a general overview of the error percentages across each conceptual understanding indicator, followed by qualitative data collection and analysis through interviews to explain and deepen the quantitative findings. This design was chosen because error percentages alone cannot sufficiently explain why a particular indicator is difficult to master; such explanations can only be obtained by directly examining students' thought processes.

Research Location, Time, and Subjects

The research was conducted at SMP Negeri 5 Bulukumba during the odd semester of the 2025/2026 academic year. The study population comprised all eighth-grade students divided into two classes: Class VIII A (25 students) and Class VIII B (23 students). Class VIII B was selected through purposive intact-class sampling. The selection rationale was based on the class characteristics showing high learning participation but low mathematics learning outcomes, making it relevant to the research focus on the gap between learning activity and conceptual understanding.

From the 23 students, six subjects were purposively selected for task-based interviews, consisting of two students in the very high category (coded S1T and S2T), two in the moderate category (S1S and S2S), and two in the very low category (S1R and S2R). Category assignment was based on conceptual understanding test scores with reference to the school's active grading criteria. Selecting subjects across three contrasting ability levels was intended to achieve maximum variation in conceptual understanding profiles.

Research Instruments

The research instruments consisted of a conceptual understanding test and a semi-structured interview protocol. The test comprised three essay items designed based on the seven indicators of mathematical conceptual understanding (Depdiknas, 2006) on the topic of number patterns. These seven indicators continue to be widely used as analytical frameworks in recent research, including Yanala et al. (2021), Rahmawati and Roesdiana (2022), and Oktapiana et al. (2025). An additional task item was used during interviews: subjects were asked to read and solve the task while answering a series of probing questions, allowing their thinking process to be observed directly rather than inferred solely from written responses. The seven indicators are presented in Table 1.

Table 1. Indicators of Mathematical Conceptual Understanding

Code	Indicator
I	Restating a concept
II	Classifying objects according to specific properties matching the concept
III	Providing examples and non-examples of a concept
IV	Presenting concepts in various mathematical representation forms
V	Using, utilizing, and selecting particular procedures or operations
VI	Applying concepts or algorithms in problem solving
VII	Developing necessary and sufficient conditions of a concept

Instrument content validity was established through evaluation by two expert validators in Mathematics Education. The evaluation covered item alignment with conceptual understanding indicators, alignment with basic competencies and curriculum scope, and language clarity. Validation results yielded an average score of 88 (high category), qualifying the instrument for use after minor editorial revisions.

Data Analysis Techniques

Quantitative data were analyzed using descriptive statistics. Student test scores were categorized based on the school's performance standards as shown in Table 2, with a Minimum Mastery Criterion (KKM) of 70.

Table 2. Student Learning Achievement Categories

Score Interval	Category
0–59	Very low
60–69	Low
70–79	Moderate
80–89	High
90–100	Very high

Classical mastery was calculated using the following formula:

$$KK = (JS / JK) \times 100\%$$

Where KK is the classical mastery percentage, JS is the number of students achieving scores greater than or equal to the KKM, and JK is the total number of students. According to school standards, classical mastery is achieved when at least 80% of students in the class reach the KKM.

The error percentage for each conceptual understanding indicator was calculated using a formula adapted from Sari (2014):

$$P = s / (s + b) \times 100\%$$

Where P is the student error percentage on the corresponding indicator, s is the sum of incorrect scores, and b is the sum of correct scores on that indicator. The P value was then interpreted using the criteria in Table 3. It should be emphasized that these criteria apply to error percentages; thus, higher categories correspond to greater student errors and lower conceptual understanding. The conceptual understanding achievement percentage was calculated as (100% – P).

Table 3. Error Rate Classification Criteria

Error Percentage Range (P)	Error Category
0% ≤ P < 20%	Very low
20% ≤ P < 40%	Low
40% ≤ P < 60%	Moderate
60% ≤ P < 80%	High
80% ≤ P ≤ 100%	Very high

Qualitative interview data were analyzed using the interactive analysis model comprising data condensation, data display, and conclusion drawing and verification (Miles et al., 2020). During condensation, interview records were transcribed and categorized by the seven indicators. During display, data were arranged into an indicator mastery matrix and narrative text. Conclusions were drawn by comparing patterns across subjects and ability levels.

Data trustworthiness was examined through technique triangulation by comparing written test data with interview responses from the same subjects. An indicator was considered mastered when both data sources yielded consistent results. In cases of discrepancy, follow-up probing questions were conducted with the respective subjects.

RESULTS AND DISCUSSION

General Conceptual Understanding Achievement

Results from the conceptual understanding test across 23 eighth-grade students in Class VIII B yielded the distribution presented in Table 4.

Table 4. Distribution of Conceptual Understanding Categories

Category	Interval	Frequency	Percentage (%)
Very high	90–100	2	8.7
High	80–89	3	13.0
Moderate	70–79	5	21.7
Low	60–69	,	,
Very low	0–59	,	,
Total		23	100.0

Note: Detailed breakdown for low and very low categories was combined in source data; their combined total is 13 students (56.5%). Classical mastery reached only 43.48% (10 out of 23 students), falling substantially short of the 80% benchmark.

Error Percentages Across Indicators

Error analysis results for each conceptual understanding indicator are presented in Table 5.

Table 5. Error Percentages and Achievement Across Conceptual Understanding Indicators

Code	Indicator	Error (%)	Achievement (%)	Error Category
I	Restating a concept	19.5	80.5	Very low
II	Classifying objects according to properties	34.7	65.3	Low
III	Providing examples and non-examples	34.7	65.3	Low
IV	Presenting concepts in various representations	23.9	76.1	Low
V	Selecting particular procedures or operations	39.1	60.9	Low
VI	Applying concepts in problem solving	39.1	60.9	Low
VII	Developing necessary and sufficient conditions	36.9	63.1	Low
	Average	32.56	67.44	Low

Based on Table 5, the overall mean error percentage across the seven indicators was 32.56%, falling into the low error category, corresponding to a conceptual understanding achievement rate of 67.44%. The lowest error rate occurred on Indicator I (Restating a concept, 19.5%), followed by Indicator IV (Presenting concepts in various mathematical representations, 23.9%). Conversely, the highest error rates occurred on Indicators V and VI (39.1% each), followed by Indicator VII (36.9%).

This pattern indicates that students are relatively more capable with reproductive indicators, recalculating and representing concepts, compared to indicators demanding procedural decision-making and applying concepts to novel situations. Indicators V, VI, and VII reside at higher cognitive levels requiring students not only to recognize concepts, but also to select appropriate procedures, apply them within problem contexts, and determine applicability conditions.

Nevertheless, caution is warranted when interpreting this difficulty ordering. With a sample size of 23 students, a single student represents approximately 4.3 percentage points. The difference between Indicator V (39.1%) and Indicators II or III (34.7%) is only 4.4 percentage points, practically equivalent to an error by a single student. Therefore, this finding should be viewed as an indicative trend rather than a definitive hierarchy of difficulty. Stronger claims require replication with larger sample sizes.

The observed weakness in Indicators V and VI aligns with Utomo et al. (2022), who noted that eighth-grade student error rates on number patterns rose sharply when items required rule formulation and application rather than simple pattern recognition. Inastuti et al. (2021) similarly identified the plan-formulation stage, equivalent to selecting procedures in this study, as the main bottleneck. A similar pattern was observed at higher levels by Septiahani et al. (2020), where errors concentrated on formula determination rather than sequence identification. This reinforces Mayasari and Habeahan's (2021) observation that explaining a concept does not automatically guarantee operational competence. Rahmawati and Roesdiana (2022) explained that such gaps often stem from instruction emphasizing procedural imitation, yielding procedural knowledge unsupported by conceptual grounding.

Indicator Mastery Profiles Across Six Interview Subjects

Triangulation results between written tests and interviews for the six selected subjects are presented in Table 6.

Table 6. Indicator Mastery Profile Across Interview Subjects

Subject	I	II	III	IV	V	VI	VII
S1T (Very High)	M	K	M	M	M	M	M
S2T (Very High)	M	M	M	M	M	K	M
S1S (Moderate)	M	M	M	K	K	K	K
S2S (Moderate)	K	K	M	M	K	K	M
S1R (Very Low)	M	TM	TM	M	TM	TM	TM
S2R (Very Low)	TM	TM	TM	M	K	K	M
Mastered Count (M)	4	2	4	5	2	1	4

Note: M = Mastered; K = Partially incorrect/incomplete; TM = Not mastered.

Both subjects in the very high category mastered six of seven indicators. S1T stumbled only on Indicator II (classifying objects), while S2T erred on Indicator VI (applying concepts in problem solving). During interviews, S1T explained pattern rules verbally and symbolically, but struggled to categorize sequences as belonging to specific pattern types.

Moderate-category subjects displayed contrasting profiles. S1S mastered the first three indicators (restate, classify, exemplify) but failed the remaining four, exemplifying a profile stagnant at initial recognition. In contrast, S2S mastered Indicators III, IV, and VII, but struggled with I, II, V, and VI. S2S presented patterns in table/visual forms and stated validity conditions, but could not rearticulate definitions in custom wording.

In the very low category, S1R mastered only Indicators I and IV, failing the rest. S2R mastered IV and VII, partially grasped V and VI, but failed I, II, and III. Interview data confirmed that both low-achieving subjects attempted problems by operating directly on visible surface numbers (e.g., adding or multiplying numbers given in the prompt) without first determining underlying pattern rules.

The bottom row of Table 6 indicates that Indicator VI was the least mastered (1 subject), followed by Indicators II and V (2 subjects each). This consistency between qualitative interview findings and quantitative test data (Table 5) provides strong technique triangulation reinforcing finding credibility.

Non-Strictly Hierarchical Indicator Mastery

An intriguing finding challenging initial assumptions emerged from subjects S2S and S2R. Both mastered Indicator VII (cognitively advanced) while failing Indicator I (foundational). For S2R, this occurred alongside non-mastery in Indicators II and III.

This demonstrates that indicator mastery does not strictly follow a linear hierarchy from Indicator I to VII. Two explanations account for this: First, some students acquire instrumental understanding, memorizing specific rules/conditions and applying them to familiar problems without possessing verbal articulation skills. Mastery in Indicator VII here is procedural rather than conceptual. This aligns with Kilpatrick's framework (Yanti et al., 2022) regarding unbalanced proficiency strands, and Devi and Amir (2021) on error variation by ability level. Second, Indicator I in essay format demands verbal and literacy skills. Rismen et al. (2020) highlighted that mathematical reasoning and communication do not always develop in tandem; language limitations can prevent conceptually intuitive students from written restatement. Sidik and Sudiana (2023) similarly observed students operating at deeper understanding layers without formalizing them verbally.

Practically, teachers cannot infer high-level indicator mastery solely from basic indicator performance, or vice versa. Conceptual diagnostic assessments must evaluate each indicator independently. This extends Mayasari and Habeahan's (2021) findings on explanation-operation dissociation by demonstrating that dissociation can occur in unexpected directions.

Key Findings and Pedagogical Implications

The primary finding of this study is that students with low conceptual understanding tend to manipulate only visible surface numbers in problem statements without selecting or executing appropriate procedures or algorithms. Students recognize that the item contains number sequences, but fail to realize that sequences are governed by generating rules that must be identified prior to calculation. This behavior matches Setiawan's (2020a) 'selective processing', where surface data are used directly to draw premature conclusions without verifying applicability across all terms. Thus, this study confirms that mechanisms previously identified in linear patterns also operate across broader conceptual understanding indicators.

These findings yield three instructional implications: First, number pattern instruction should begin with rule discovery activities rather than immediate presentation of n-th term formulas. Students require opportunities to observe sequences, formulate conjectures, test hypotheses, and generalize rules (Wulandari & Machromah, 2024). Second, early prerequisite diagnostic assessment is vital. Sudirman (2023) showed that authentic assessments emphasizing process over final answers enhance conceptual understanding. Seven-indicator diagnostic tools can map specific individual weaknesses for targeted intervention.

Third, established misconceptions should be addressed through cognitive conflict strategies that directly confront errors. Setiawan (2020b) demonstrated that students rectify generalisation errors when guided to re-check data adequacy, and error-based discussion models effectively improve conceptual understanding (Setiawan & Mustangin, 2020). Contextual approaches also effectively strengthen number concept understanding (Nainggolan et al., 2024). Combining diagnostic pre-assessment with error-focused learning provides a more effective remedy than merely increasing practice drill volume.

Research Limitations

Several limitations should be noted. First, the sample was restricted to a single class in one school, precluding broad population generalisation. Second, the small sample size makes percentage differences across indicators sensitive to single-student response shifts. Third, indicator mastery was evaluated by a single research team; incorporating independent inter-raters would enhance scoring reliability. Fourth, non-cognitive factors (Nurhandita et al., 2021; Miatun & Ulfah, 2023) were not measured. Future research should expand sample sizes across multiple schools, employ multi-rater rubric scoring per indicator, and incorporate affective variables.

CONCLUSION

Eighth-grade students at SMP Negeri 5 Bulukumba exhibited an average error percentage of 32.56% (conceptual achievement of 67.44%) in solving number pattern problems. Classical mastery reached only 43.48%, with over half the students falling into low and very low categories. The lowest error rate occurred on restating concepts (19.5%), whereas the highest errors occurred on selecting procedures and applying concepts in problem solving (39.1% each). Minor percentage gaps across indicators require cautious difficulty ranking.

Qualitative analysis across six interview subjects demonstrated that indicator mastery is not strictly hierarchical: some students mastered advanced indicators while failing basic ones. The primary behavioral finding is that low-performing students rely on surface number manipulation without selecting appropriate procedural rules.

Mathematics teachers are advised to implement indicator-based diagnostic assessments prior to instruction and emphasize pattern discovery before introducing formulas. Future researchers should expand sample sizes and adopt multi-rater scoring rubrics per indicator to enhance data validity and reliability.

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