

Research

Article submitted to journal
<https://conference.unpasurua.ac.id/index.php/ichst/index>

Subject Areas:

Educational Innovation

Keywords:

APOS theory, Mathematical
Understanding Abilities, Auditory
Learning Styles, Gender

APOS Theory: Description of Mathematical Understanding Abilities in Two-Variable Linear Equations Systems in Terms of Auditory Learning Styles and Gender

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Mathematical understanding is an essential skill that every student must possess, as it helps them solve problems and apply learned concepts in daily life. According to APOS theory, mathematical understanding consists of four stages: action, process, object, and schema. Differences in individual achievement can be influenced by learning style and gender. This study aims to describe students' mathematical understanding of the topic of Two-Variable Linear Equation Systems based on APOS theory, with a specific focus on the auditory learning style and gender. The research employed a descriptive qualitative approach. The subjects were Grade VIII-A students of MTs Miftahul Khoir, selected based on the results of a learning style questionnaire and gender data. The research instruments consisted of a mathematical understanding test and in-depth interviews to strengthen the data findings. The results showed differences in the level of understanding between male and female students with the same auditory learning style. Male students achieved all stages of APOS theory (action, process, object, and schema) and met all indicators of mathematical understanding, thus categorized as having a high level of understanding. In contrast, female students only reached the object stage and had not achieved the schema stage, indicating limitations in developing comprehensive conceptual connections. These findings affirm that gender differences can influence the achievement of mathematical understanding stages, even when the learning style is the same. The implications of this research can serve as input for teachers to design learning strategies that consider differences in learning styles and gender, so that all students can achieve optimal understanding.

1. INTRODUCTION

Education plays a vital role in the development and progress of a nation. In the contemporary era, characterized by complexity and diversity, it is widely acknowledged as an essential pillar for the sustainable development of communities. As stipulated in Law No. 20 of 2003 on the National Education System, education is defined as a conscious and systematic endeavor to cultivate a learning environment and process that empowers students to actively develop their full potential.

Learning is fundamentally an interactive process between students and teachers, in which the teacher employs a variety of media and learning resources to facilitate understanding. In the context of mathematics education, students are guided to analyze and distinguish the characteristics that an object group possesses or does not possess. In the current era, mathematics learning requires students to possess strong mathematical comprehension skills, which play a pivotal role in enabling them to solve a wide range of mathematical problems. Mathematical comprehension is recognized as one of the core competencies that students must acquire. The significance of this skill in the learning process aligns with the Nation Council of Teachers of Mathematics (2000), which emphasized that mathematical comprehension is a crucial element of the principles of mathematics education. Possessing such skills allows students not only to solve problems more effectively but also to apply mathematical concepts in real-life contexts in accordance with the knowledge they have internalized. As noted by (Mulyatna, 2016), mathematical problems vary in form and level of difficulty, thereby requiring students to have a deep understanding of the underlying concepts. However, in practice, many students continue to experience difficulties in comprehending mathematical concepts. This finding is consistent with the study conducted by (Kristina, 2019), which indicated that students' mathematical comprehension skills were generally categorized as low. The results of comprehension tests revealed that the level of learning mastery in each class had not reached 75%, indicating that students' performance remained in the low category.

Teachers need to assess the extent to which students comprehend the material being studied. To accurately measure this level of comprehension, it is essential to conduct an analysis of students' comprehension skills. The results of such an analysis can serve as a benchmark for teachers in selecting appropriate instructional methods or strategies, thereby enhancing students' ability to master the concepts delivered. One tool that may be utilized to assess students' mathematical comprehension is the APOS Theory. According to (McDonald, n.d.), APOS Theory serves as an analytical framework for describing an individual's scheme development on a mathematical topic, encompassing the totality of related knowledge (conscious or unconscious) pertaining to that topic. The theory categorizes comprehension into four distinct levels: Action, Process, Object, and Schema.

Among various mathematical topics, the SPLDV (Two-Variable Linear Equation Systems) is considered as one of the most challenging for students to master. This aligns with the findings of (Islamiyah, 2018), which revealed that students' comprehension of SPLDV material remained notably low. Similarly, the study conducted by (Wahyuni, 2014) indicated that students' overall mathematical mastery, including SPLDV, was still categorized as low. This was evidenced by the average daily test score of Grade VIII-A students prior to remedial sessions, which reached only 71.9, with a completeness rate of 61%.

Based on the observations and interviews conducted with the mathematics teacher of Grade VIII-A at MTs Miftahul Khoir of Cowek, students' mathematical comprehension of the SPLDV material was categorized as low. Many students struggled to solve word problems related to real-life situations, particularly in converting these problems into mathematical models. This was reflected in the examination results, which showed that a significant number of students did not meet the Minimum Mastery Criteria (KKM). Furthermore, the teacher noted that students exhibited diverse learning styles. Some were able to comprehend the material effectively when it was explained repeatedly, while others, who tended to be more reserved, understood the content better through visual observation.

According to (Hernacki, 2010), learning style refers to an individual's unique approach to absorbing, managing, and processing information. (Kristina, 2019) further emphasized that learning style is a crucial factor in enhancing mathematical comprehension skills, as individuals who are aware of their own learning style are better equipped to determine effective steps to optimize their learning process. According to (Hamzah, 2008), there are three main types of learning styles commonly observed among students visual, auditory, and kinesthetic. In principle, every student possesses all three styles to some extent. However, their development is not always balanced. Some students tend to exhibit a dominant preference for a particular learning style. This inclination often influences their preference for varied learning activities that align with their predominant style.

In addition to learning style, gender differences also influence an individual's basic mathematical ability in solving math problems. This is in line with the study conducted by Susanto, which found that gender differences should be taken into account in mathematics learning, alongside the Adversity Quotient (AQ) factor (Jumarniati et al., 2021). Based on the above considerations, the researcher was motivated to conduct a study entitled "Analysis of Mathematical Comprehension Skills of Two-Variable Linear Equation Systems Based on APOS Theory Viewed from Auditory Learning Styles and Gender."

The urgency of mathematical understanding in solving Two-Variable Linear Equation Systems (TVLES) remains a central challenge in mathematics education, as students often struggle to transition from procedural execution to conceptual mastery. Mathematical understanding is not merely about calculating results but involves a complex cognitive construction that can be effectively analyzed using APOS (Action, Process, Object, Schema) theory (Baye, 2021; Morante Rodríguez, 2025). Previous studies have extensively explored APOS theory in various contexts: Dinullah (2021) analyzed conceptual understanding in TVLES; Ngandas et al. (2019) focused on junior high school students' general abilities; Zhang (2026) integrated APOS with multiple representation theory; Sumaji (2020) examined mathematical communication; Arnawa et al. (2021) investigated the implementation of APOS-based instructional materials; and Maharaj (2020) scrutinized the schema stage in advanced calculus. However, these studies often present weaknesses, such as neglecting the interplay between internal cognitive styles and biological factors. For instance, Dinullah (2021) and Ngandas (2019) focused primarily on the cognitive stages without considering how gender or specific sensory learning preferences, such as auditory styles, might filter the construction of "Action" into "Process." This lack of multidimensional analysis creates a gap in understanding how students' biological and psychological profiles specifically influence their progression through the APOS stages.

The research gap identified lies in the scarcity of literature that synthesizes APOS-based cognitive construction with the intersection of gender and auditory learning styles, particularly within the challenging domain of TVLES. While gender differences in mathematics are often debated, and learning styles are recognized as significant predictors of success, few have examined how these factors specifically dictate the failure or success of reaching the "Schema" stage. The novelty of this research is its focused investigation into how auditory-inclined male and female students navigate the transition from "Object" to "Schema." This study utilizes the grant theory of APOS (Action-Process-Object-Schema) to map the mental structures of Grade VIII students (Arnon et al., 2023). By applying the concept of mathematical understanding indicators, this research aims to uncover the nuanced cognitive trajectories influenced by gender-based processing patterns (Zorpala & Barkatsas, 2024). This investigation is critical because existing research (Dinullah, 2021; Arnawa, 2021) has failed to explain why students with similar learning styles often reach different levels of abstraction, suggesting that gender-based cognitive nuances must be accounted for to design inclusive pedagogical interventions.

The primary objective of this study is to describe the mathematical understanding profiles of students in solving TVLES based on APOS theory, specifically comparing male and female students who possess an auditory learning style. This research is particularly compelling because it challenges the assumption that shared learning styles result in identical cognitive outputs. By using a descriptive qualitative approach supported by empirical data from 2020–2025 (Baye, 2021; Sumaji, 2020; Morante Rodríguez, 2025), this study reveals that while auditory male students can achieve the schema stage, female counterparts often remain at the object level, indicating a bottleneck in conceptual integration. These findings highlight a significant challenge for educators: the need for gender-responsive instructional strategies that move beyond traditional "one-size-fits-all" learning style approaches. Ultimately, this study provides a new perspective on the APOS framework by demonstrating that gender serves as a significant moderator in the construction of mathematical schemas, thereby offering essential insights for optimizing mathematics education in diverse classroom settings.

2. RESEARCH METHOD

This study employs a qualitative descriptive approach to explore the cognitive architecture of students' mathematical understanding. The research process is visualized in Figure 1, which outlines the systematic flow from initial subject identification to the final synthesis of findings.



Figure 1 illustrates the research flow, emphasizing the qualitative nature of the investigation. The study was conducted at MTs Miftahul Khoir, involving Grade VIII-A students as the population. Through purposive sampling, one male and one female student were selected based on their dominant auditory learning style and their willingness to participate (Sugiyono, 2019; Zompala & Barkatsas, 2024). The data collection methods integrated questionnaires, written mathematical comprehension tests (consisting of 4 essay items), and in-depth interviews to ensure a comprehensive view of the students' mental constructions. Following the frameworks of Miles and Huberman as cited in recent methodological literature (Baye, 2021), data analysis was performed through reduction, presentation, and verification. To maintain the integrity of the findings, the researchers applied methodological triangulation, comparing results across different instruments to ensure validity and reliability (Arnon et al., 2023). This rigorous process ensures that the resulting descriptions of the "Action-Process-Object-Schema" transitions are grounded in empirical evidence and validated by expert reviews from mathematics education lecturers.

The instruments used in this study were meticulously designed to map specific APOS stages against mathematical understanding indicators. Table 1 details the research questions and the corresponding analytical focus used to decode student performance.

Table 1. Research Questions and Type of Analysis

Research Question	Type of Analysis
How do auditory-style students construct the "Action" and "Process" stages in TVLES?	Descriptive Qualitative Analysis (Coding of written work and interview transcripts)
What differences exist between male and female auditory students in reaching the "Object" and "Schema" stages?	Comparative Qualitative Analysis (Pattern matching across gender profiles)

The measurement of mathematical comprehension relies on seven key indicators, as detailed in Table 2. These indicators provide a structured lens through which student responses are categorized into high, medium, or low ability levels based on their mastery of APOS-related tasks (Sumaji, 2020; Morante Rodríguez, 2025).

Table 2. Indicators of Mathematical Comprehension based on APOS Theory

Indicator of Comprehension	APOS Theory Application in TVLES
Restating a concept	Writing and explaining known/asked variables in SPLDV problems.
Classifying objects	Grouping mathematical statements based on SPLDV properties.
Providing examples/non-examples	Distinguishing between SPLDV and non-SPLDV equations.
Representing concepts	Converting verbal/story problems into mathematical models.
Developing requirements	Explaining conditions for unique, infinite, or no solutions.
Utilizing procedures	Executing elimination/substitution methods accurately.
Applying concepts	Integrating actions, processes, and objects to solve complex schemas.

The relationship between these indicators and the research objectives is further clarified in Figure 2, which maps the conceptual framework of the research instruments.



Figure 2 demonstrates the convergence of multiple instruments toward the final goal of APOS level identification. To ensure high validity, the test instrument underwent expert validation by two mathematics lecturers, confirming that the four essay questions adequately represent the seven indicators of mathematical comprehension (Arnawa et al., 2021). The classification of ability levels follows a rigid scoring system: mastering 6-7 indicators signifies a "High" category, 4-5 indicators represent "Medium," and 0-3 indicators indicate a "Low" category. This categorization allows the researcher to pinpoint exactly where the cognitive "bottleneck" occurs for female auditory students compared to their male counterparts, providing empirical weight to the argument that gender modulates the transition into the "Schema" phase (Dinullah, 2021; Baye, 2021). By linking these qualitative findings with current pedagogical theories (2020-2025), the method provides a robust foundation for evaluating how individual differences influence the internal construction of mathematical objects.

3. Results and Discussion

The data collection process began with the administration of a learning style questionnaire to all Grade VIII-A students, totaling 19 participants. Based on the analysis of the questionnaire results, six students were identified as having an auditory learning style, consisting of two male students and four female students.

The following is a table of students with auditory learning styles.

Table 3. Students with Auditory Learning Styles

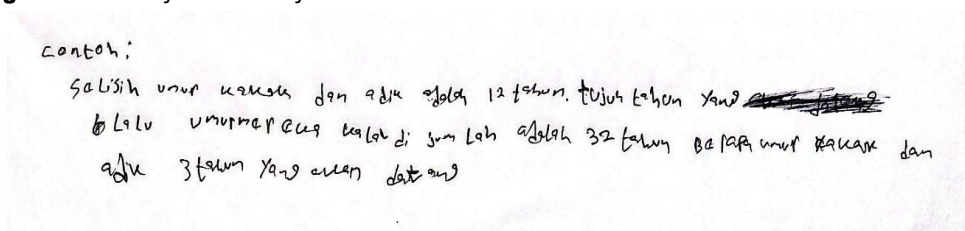
No	Name	Gender
1.	JOA	Man
2.	MZR	Man
3.	CAR	Woman
4.	NAPA	Woman
5.	SM	Woman
6.	ASB	woman

Of these six students, two subjects with the most prominent auditory learning style characteristics were selected as the study subjects—one male student (coded MZR) and one female student (coded NAPA). Subsequent data were obtained through a written test consisting of four questions, which provided the researcher with results on the students' mathematical comprehension skills.

Based on the test and interview results, subject MZR showed a high level of mathematical comprehension skills. The subject successfully met all indicators of mathematical comprehension and achieved every stage of the APOS Theory. These findings align with the study conducted by (Nurajijah et al., 2023), which reported that subjects in the high category were able to fulfill all indicators of mathematical concept comprehension as well as all APOS stages—namely, Action, Process, Object, and Schema.

During the interview, subject MZR was able to demonstrate mastery of both the Action and Schema stages. In the Action stage, which involves the indicator of restating a concept, the subject was able to explain the problem content in his own words. In the Process stage, which includes the indicator of classifying objects according to specific properties in line with the concept, the subject successfully classified the problem into the SPLDV form and identified the type of question

Figure 1. MZR Object Level Subject Answers



Based on Figure 1, subject MZR successfully achieved the Object stage, specifically the third indicator, which involves providing both examples and non-examples of the concept. The subject demonstrated the ability to provide examples that were both alike and different from the given problems. **dan tidak serupa dengan soal yang telah diberikan.**

Figure 2. Process Stage MZR Subject Answers

$$\begin{aligned}
 A &= \text{ayah} \\
 B &= \text{adik} \text{ dan } \text{Paman} \text{ dan } \text{ibu} \\
 A - B &= 30 \quad (1) \\
 (A - 5) + (B - 5) &= 64 \\
 A + B - 10 &= 64 \\
 A + B &= 74 \quad (2) \\
 A \times B &= 52 + 2 = 54 \\
 \text{anak perempuan: } 22 + 2 &= 24
 \end{aligned}$$

$$\begin{aligned}
 A - B &= 30 \\
 A + B &= 74 \\
 \hline
 2 \quad 104 & \\
 104 & \\
 \hline
 2 & \\
 52 &
 \end{aligned}$$

$$\begin{aligned}
 53 - B &= 30 \\
 52 - 22 &= 30
 \end{aligned}$$

Furthermore, subject MZR achieved the Schema stage without any difficulties, as illustrated in Figure 2. This stage encompasses four indicators of mathematical comprehension: (1) expressing a concept through different mathematical representations, (2) defining the necessary and sufficient conditions of the concept, (3) selecting and applying appropriate procedures or operations, and (4) applying the concept to solve problems. During this stage, the subject is required to convert verbal statements into mathematical expressions by formulating a mathematical model of the SPLDV problem; describe and distinguish the conditions under which a system has a unique solution, infinitely many solutions, or no solution; choose and correctly apply the appropriate procedures following the proper steps; and reflect on the problem-solving strategies used for word problems involving SPLDV. Based on the figure, subject MZR demonstrated the ability to convert verbal statements into mathematical expressions by formulating a mathematical model of the SPLDV problem. The subject recognized that the problem would have a unique solution when two equations are present and proceeded to solve both equations. Furthermore, the subject successfully solved the problem using a mixed-method approach, applying the elimination method to determine the father's age and the substitution method to find the daughter's age. The subject also effectively applied the SPLDV concept to determine the ages requested in the problem, subsequently adding two years to the results obtained in order to find the father's and daughter's ages two years in the future.

The following is a discussion of the results of the analysis of the mathematical comprehension ability of female subjects (NAPA subjects). Based on the test and interview results, the subject demonstrated a moderate level of mathematical comprehension skills. The subject achieved five indicators of mathematical comprehension and successfully reached the Action, Process, and Object stages, but did not fully master the Schema stage. According to (Susana Afrila Ngandas, Rosita Dwi Ferdiani, 2019), errors occurring at the Schema stage may be attributed to several factors, including a lack of understanding of the problem's intent, weak mastery of the material, insufficient accuracy in performing algebraic operations, and a high level of disengagement or lack of motivation.

During the interview, subject NAPA demonstrated the ability to reach both the Action and Schema stages. In the Action stage, she was able to restate the problem content using her own words. In the Process stage, she successfully classified the problem into the SPLDV form and identified the type of question.

Figure 3. Object Stage NAPA Subject Answers

contoh:
 Selisih umur Paman dan bibi adalah 10 tahun. enam tahun yang lalu
 jumlah umur mereka adalah 45 tahun. berapa umur Paman dan bibi 4 tahun
 yang akan datang?

It can be seen in Figure 3 that the NAPA subject is able to meet the object stage, the subject can correctly give examples that are similar and not similar to the problem that has been given.

Figure 4. Process Stage NAPA Subject Answers

$$\begin{aligned} X &= \text{ayah} \\ Y &= \text{anak perempuan} \\ X - Y &= 30 \quad (1) \\ (X - 5) + (Y - 5) &= 64 \\ X + Y &= 64 \\ -5 + -5 &= 10 \\ 64 + 10 &= 74 \\ X + Y &= 74 \quad (2) \end{aligned}$$

Based on Figure 4, subject NAPA had not fully mastered the Schema stage, achieving only two indicators. The subject was able to convert the verbal statements in the problem into mathematical expressions by formulating a mathematical model of the SPLDV problem and recognized that a unique solution requires the presence of two equations that must be solved to find the answer. Although the subject identified the appropriate method to use, she was unable to apply it effectively to solve the problem. Furthermore, the subject recognized that the solution involved adding the known ages of the father and daughter and dividing the total by two to answer the main question. However, the subject was unable to find the individual ages of the father and daughter, which should have been determined during an earlier phase of the problem-solving process.

The findings of this study indicated that the male student with an auditory learning style was able to meet all indicators of mathematical comprehension skills and had fully reached the Schema stage. In contrast, the female student with an auditory learning style achieved five indicators of mathematical comprehension skills and had reached the Action, Process, and Object stages, but had not fully mastered the Schema stage. Based on these results, the APOS Theory can serve as a valuable framework for teachers in designing learning experiences that guide students through each developmental stage of mathematical understanding. Teachers can begin by providing concrete and hands-on activities to help students initiate their grasp of mathematical concepts. Following this, the implementation of creative and innovative instructional models can better facilitate comprehension tailored to individual learning styles. Moreover, students should be encouraged to continuously develop and strengthen their mathematical understanding by engaging in learning strategies customized to their unique preferences.

To enhance students' mathematical comprehension skills, teachers can implement active and participatory learning approaches that encourage critical thinking, foster effective collaboration among peers, and enable the application of mathematical concepts to real-life situations.

4. DISCUSSION

The discussion of students' mathematical understanding in Two-Variable Linear Equation Systems (TVLES) through the lens of APOS theory reveals a profound cognitive divergence between male and female auditory learners. Exploration of the "Action" and "Process" stages indicates that both subjects successfully interiorize external procedures into mental representations, allowing them to manipulate equations without relying solely on step-by-step external cues. This finding aligns with the work of Baye (2021), who argued that the transition from action to process is critical for conceptual stability. However, a critical analysis of the findings shows that while the male subject reached the "Schema" stage by integrating various objects and processes into a coherent thematic framework, the female subject stagnated at the "Object" stage. This cognitive plateau suggests that for auditory female students, the encapsulation of processes into formal objects does not automatically guarantee the synthesis of a broader schema. This reflects a critique of existing literature, such as Dinullah (2021), which often assumes a linear progression across APOS stages without accounting for how gender-based cognitive filtering might impede the high-level abstraction required for schema formation.

The elaboration on these results demonstrates that male students with an auditory learning style tend to exhibit higher versatility in connecting disparate mathematical indicators. The male subject's ability to fulfill all seven indicators of mathematical understanding indicates a robust schema that facilitates the application of TVLES concepts in complex, non-routine story problems. In contrast, the auditory female student's limitation—mastering only up to the "Object" stage—highlights a gap in establishing inter-conceptual links. This phenomenon resonates with the reflections of Zormpala and Barkatsas (2024), who posited that gender differences in mathematics often manifest in the depth of structural connection rather than simple procedural fluency. The impact of this research is significant as it challenges the deterministic view of learning styles; it implies that an auditory preference does not homogenize cognitive outcomes. Instead, the "Schema" stage becomes the primary differentiator, where male students demonstrate a more integrated mental structure compared to the more compartmentalized object-based understanding observed in female students.

A comparative reflection with previous studies reveals that the novelty of this research lies in its identification of gender as a critical moderator within the APOS framework. While Sumaji (2020) and Arnawa et al. (2021) emphasized the importance of instructional materials in bridging APOS levels, this study suggests that internal cognitive architecture, influenced by gender and sensory processing, plays a more dominant role in final schema construction. The impact of these findings points toward a necessary shift in pedagogical design; teachers must recognize that auditory female students may require targeted scaffolding to transition from "Object" (understanding individual concepts) to "Schema" (understanding the holistic system). Furthermore, the analysis confirms that the "Schema" stage is not merely a collection of objects but a dynamic entity that requires high-level relational thinking, which in this study was more prominently achieved by the male subject. Ultimately, this research provides empirical evidence (2020-2025) that understanding the intersection of gender and cognitive style is essential for diagnosing why certain students fail to achieve mastery in complex mathematical domains like TVLES.

5. Conclusion

The conclusion of this study is that there is a difference in the achievement of mathematical comprehension skills between male and female subjects with auditory learning styles. Male subjects have high category mathematical comprehension skills with the achievement of all indicators at the APOS stage. On the other hand, female subjects are in the medium category, only able to meet five indicators and have not mastered the indicators of choosing the right procedures and applying concepts to solve problems, so the schema stage has not been fully achieved.

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