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Students' Algebraic Thinking in Solving Algebraic Problems Across VAK Learning-Style Preferences

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ABSTRACT

Algebraic thinking is an essential component of mathematics learning because it enables students to represent relationships, use variables, construct mathematical models, and solve problems systematically. However, students may demonstrate different ways of processing and communicating algebraic ideas. This study aimed to describe students' algebraic thinking in solving algebraic problems across visual, auditory, and kinesthetic (VAK) learning-style preferences. A descriptive qualitative design was employed. The initial participants were 30 seventh-grade students from a junior high school in Surabaya, Indonesia. Based on the results of a learning-style questionnaire and an algebraic thinking test, three students with comparable mathematical abilities were purposively selected to represent visual, auditory, and kinesthetic learning-style preferences. Data were collected through a learning-style questionnaire, algebraic thinking tests, and semi-structured interviews and were analyzed through data reduction, data presentation, and conclusion drawing. The findings revealed distinct patterns across the three cases. The visual student demonstrated appropriate algebraic modeling and calculation but did not explicitly record some initial problem information in the written solution. The auditory student constructed appropriate mathematical models and performed calculations correctly but showed incomplete written organization and did not provide explicit final conclusions. In contrast, the kinesthetic student produced the most complete and systematically organized written solution, from identifying problem information to formulating mathematical models and stating final conclusions. These findings indicate that the three students differed primarily in how they represented, organized, and communicated their algebraic thinking processes. The study highlights the importance of examining students' solution processes through multiple forms of evidence rather than relying solely on final answers.

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INTRODUCTION

Algebra is a fundamental domain of mathematics that supports students in representing quantitative relationships, identifying mathematical structures, and solving increasingly complex problems. Its role extends beyond symbolic manipulation because algebraic ideas are closely connected with arithmetic, geometry, statistics, and other areas of mathematics (Kusuma et al., 2024). In mathematics education, algebraic thinking therefore needs to be developed as a form of reasoning through which students interpret relationships, use variables, construct representations, and generalize mathematical situations. Algebraic thinking should not be introduced merely as the manipulation of symbols but should be connected with students' previous arithmetic experiences and used as a means of representing and analyzing mathematical situations (Manly & Ginsburg, 2010).

Developing these abilities is particularly important because algebraic thinking provides a foundation for more advanced mathematical reasoning (Sibgatullin et al., 2022).

Despite its importance, students often experience difficulties when moving from arithmetic reasoning to algebraic representation. Algebra requires them to work with unknown quantities, understand variables, establish relationships among quantities, and manipulate symbolic expressions while maintaining the meaning of the original problem. Algebraic thinking consequently involves several interconnected processes rather than the application of a single computational procedure. It includes the ability to represent unknown quantities symbolically, construct algebraic relationships, manipulate expressions, and organize reasoning into a meaningful solution process (Bozkurt & Özmusul, 2024; Sibgatullin et al., 2022). These demands make it important to examine not only whether students obtain correct answers but also how they interpret, represent, and communicate their reasoning during problem solving.

Students may approach mathematical problems in different ways. One perspective commonly used to describe such differences is learning-style preference, including visual, auditory, and kinesthetic tendencies. Visual learners tend to rely on written or graphical representations, auditory learners often engage with verbal explanations and discussions, and kinesthetic learners tend to prefer direct involvement and activity-based experiences. Differences among these preferences may be reflected in how students receive, organize, and communicate mathematical information (Sulisawati et al., 2019). Previous studies have also shown that individual learning and cognitive characteristics can be associated with variations in mathematical problem-solving processes and representations (Rahmawati et al., 2019; Sheromova et al., 2020).

A number of studies have examined algebraic thinking from different learner characteristics. Rahmawati et al. (2019), for example, investigated algebraic-thinking profiles in mathematical problem solving, while Yusrina et al. (2023) examined algebraic thinking in relation to reflective cognitive style. Kusuma et al. (2024) analyzed students' algebraic-thinking processes in solving linear equations based on cognitive systems, demonstrating the importance of examining the reasoning underlying students' written solutions. Other studies have considered learning-style-related characteristics in mathematics. Sulisawati et al. (2019) reported differences among visual, auditory, and kinesthetic students in understanding mathematical problems, whereas Rosida and Masduki (2023) explored students' algebraic thinking from the perspective of Kolb's learning styles. Agustina et al. (2024) further examined students' critical thinking in algebraic problem solving from the perspective of a visual learning style. Collectively, these studies indicate that students' individual characteristics can provide a useful perspective for examining variation in mathematical reasoning.

However, an important methodological issue remains in interpreting such differences. Variations in the completeness of students' written answers do not necessarily correspond directly to differences in the underlying algebraic-thinking processes. A student may omit conventional written components but still be able to explain the mathematical relationships and reasoning verbally. Conversely, a well-structured written solution may make a student's reasoning more visible without necessarily indicating a fundamentally different level of conceptual understanding. Therefore, analyses of algebraic thinking need to distinguish between the mathematical processes demonstrated by students and the forms through which those processes are communicated. Examining written solutions together with students' verbal explanations can provide a more complete account of how algebraic knowledge is constructed and used in problem solving (Kusuma et al., 2024).

Against this background, the present study addresses a specific gap in the existing body of work by examining algebraic thinking across visual, auditory, and kinesthetic learning-style preferences through a qualitative comparison of students' written solutions and interview explanations. While previous studies have investigated algebraic thinking in relation to cognitive styles, mathematical ability, or other learning-style frameworks (Kusuma et al., 2024; Rosida & Masduki, 2023; Yusrina et al., 2023; Husna, et al., 2024; Rahmatika, et al., 2022; Musnaini, et al., 2022), the present study focuses specifically on how core algebraic-thinking processes are demonstrated and communicated across three VAK cases. The novelty of the study lies not in assuming that VAK preferences determine students' algebraic ability, but in distinguishing between evidence of algebraic processes—such as symbolic interpretation, modeling, and analytical manipulation—and differences in how those processes are organized and communicated in written and verbal forms. This distinction is important because the assessment of algebraic thinking should focus on students' reasoning processes rather than solely on the completeness of their written responses or final answers.

A more detailed understanding of students' algebraic reasoning can also contribute to instructional practice. Effective algebra instruction needs to connect problem-solving activities with conceptual understanding and provide opportunities for students to explain relationships, construct representations, and justify their procedures (Jamil et al., 2025). From this perspective, examining multiple forms of students' reasoning can help teachers identify which aspects of algebraic thinking are actually demonstrated and which aspects may simply be less visible in a particular form of communication. Such information may support instructional practices that provide students with varied opportunities to express mathematical reasoning through symbolic representations, written explanations, and verbal justification.

Accordingly, this study aims to describe and compare the algebraic-thinking processes demonstrated by seventh-grade students representing visual, auditory, and kinesthetic learning-style preferences when solving contextual algebraic problems. Specifically, the study examines how the three participants demonstrate abstraction, modeling, analytical thinking, organization, and, where sufficiently elicited by the tasks, generalization and dynamic thinking through their written solutions and interview explanations. By conducting within-case and cross-case analyses, the study seeks to identify similarities and differences in the ways the participants represent, organize, and communicate algebraic reasoning without treating learning-style preference as a causal determinant of mathematical ability.

METHOD

This study employed a descriptive qualitative design to examine students' algebraic thinking processes in solving algebraic problems across visual, auditory, and kinesthetic (VAK) learning-style preferences. The qualitative approach was selected because the study focused on describing how students interpreted problem information, represented quantities symbolically, constructed algebraic models, performed algebraic operations, and communicated their solution processes rather than on comparing numerical achievement scores. Data were obtained from a learning-style questionnaire, an algebraic thinking test, and semi-structured interviews. The written responses and interview data were used complementarily to provide a detailed description of each participant's algebraic thinking process.

Participants

The participants were seventh-grade students from one junior high school in Surabaya, Indonesia. At the initial stage, 30 students from one seventh-grade class completed a VAK learning-style questionnaire and an algebraic thinking test. The questionnaire was used to identify students' learning-style preferences, while the algebraic thinking test provided preliminary information about their performance in solving algebraic problems.

hree students were subsequently selected purposively for in-depth analysis. Each participant represented one dominant learning-style preference: visual, auditory, or kinesthetic. The selection was guided by three criteria: (1) the student had received introductory algebra instruction, (2) the student demonstrated a distinguishable learning-style preference based on the questionnaire results, and (3) the student was able and willing to explain the reasoning underlying the written solution during the interview. Mathematical performance on the preliminary algebraic thinking test was also considered during the selection process to avoid selecting participants with substantially different levels of mathematical performance.

Based on these criteria, HFF was selected to represent the visual learning-style preference, AFA the auditory learning-style preference, and SSSP the kinesthetic learning-style preference. The use of one participant from each category was intended to support an in-depth description and cross-case comparison of the algebraic thinking processes demonstrated by the three participants. Accordingly, the findings were interpreted as characteristics of the individual cases examined rather than as generalizations about all students with visual, auditory, or kinesthetic learning-style preferences.

Instruments

Three instruments were used to collect the data: a VAK learning-style questionnaire, an algebraic thinking test, and semi-structured interviews. The questionnaire was used to identify students' learning-style preferences, whereas the algebraic thinking test and interviews were used complementarily to examine how the selected participants understood, represented, and solved algebraic problems. The written test provided observable evidence of the participants' solution processes, while the interviews were used to clarify and elaborate on reasoning that was not fully expressed in their written responses.

VAK Learning-Style Questionnaire

The VAK learning-style questionnaire was used to identify students' preferences for receiving and processing information through visual, auditory, and kinesthetic modalities. The instrument was adapted from the VAK framework and modified to suit the characteristics and learning context of seventh-grade students. It consisted of 30 statements distributed equally across the three learning-style categories, with 10 statements representing each category.

The visual dimension reflected students' preferences for learning through written information, images, colors, symbols, and other visual representations. The auditory dimension represented preferences for learning through listening, verbal explanation, discussion, and spoken information. The kinesthetic dimension reflected preferences for learning through physical engagement, direct practice, movement, and experience-based activities. The indicators used to characterize the three learning-style preferences are presented in Table 1.

Table 1. Indicator of VAK learning-style preferences

Learning-Style Preferences	Indicators	Number of items
Visual	Understanding information through pictures or written representations; using reading and note-taking to support learning; attending to visual learning media; using colors or symbols; and recalling information primarily from what is seen.	10
Auditory	Understanding information through verbal explanations; preferring learning through listening; recalling spoken information; engaging in discussion or verbal explanation; and responding positively to sound-based learning activities.	10
Kinesthetic	Learning through direct practice or experimentation; engaging in physical activities or movement; learning from concrete experiences; preferring practice-oriented activities; and responding positively to learning that involves physical engagement	10

The questionnaire results were used as an initial basis for identifying each student's dominant learning-style preference. These results were not treated as measures of mathematical ability but were used to support the purposive selection of participants representing visual, auditory, and kinesthetic preferences.

Algebraic Thinking Test

The algebraic thinking test was used to examine the participants' reasoning processes when solving contextual algebraic problems. The test consisted of two open-ended problems that required students to interpret quantitative information, represent quantities using variables, construct algebraic expressions, simplify the expressions, substitute given values, and determine the final results. Open-ended items were used because they enabled the participants to demonstrate not only their final answers but also the mathematical steps and representations involved in reaching those answers.

Students' written responses were analyzed using six theoretical indicators of algebraic thinking: generalization, abstraction, modeling, dynamic thinking, analytical thinking, and organization. Each indicator was operationalized through observable evidence to maintain consistency between the conceptual definition and the empirical interpretation of students' responses. Because the two test items did not necessarily provide an equal opportunity to elicit every indicator, the absence of observable evidence was not automatically interpreted as an inability to demonstrate the corresponding form of algebraic thinking. The operational definitions are presented in Table 2.

Table 2. Algebraic Thinking Indicators

Indicator	Operational Definition	Observable Evidence
Generalization	The ability to identify relationships, regularities, or common structures among quantities and to express these relationships as a general mathematical rule or statement.	The student identifies a recurring relationship or pattern, explains relationships among quantities, or formulates a generalized algebraic rule from the given situation
Abstraction	The ability to interpret and use symbols or variables to represent quantities and relationships in a mathematical situation.	The student explains the meaning of a variable, uses the variable consistently to represent a quantity, and appropriately connects the symbolic representation with the problem context.
Modeling	The ability to translate information and quantitative relationships in a contextual problem into an appropriate algebraic expression or equation.	The student identifies relevant quantitative relationships and represents them correctly using an algebraic expression or equation.
Dynamic Thinking	The ability to consider, develop, or use alternative strategies or representations when solving an algebraic problem.	The student proposes, explains, compares, or applies more than one valid strategy or representation, or appropriately modifies a strategy during problem solving.

Analytical Thinking	The ability to manipulate algebraic expressions logically and perform appropriate mathematical operations to obtain a solution.	The student simplifies algebraic expressions, performs operations correctly, substitutes given values appropriately, and demonstrates logical connections between successive solution steps.
Organization	The ability to arrange and communicate the problem-solving process in a coherent, logical, and traceable sequence.	The student presents the mathematical model, operations, intermediate results, and final result in an order that allows the reasoning process to be followed clearly.

To support consistent interpretation of the written and interview data, evidence for each indicator was classified as Demonstrated (D), Partially Demonstrated (PD), Not Demonstrated (ND), or Not Elicited (NE). *Demonstrated*indicated clear and consistent evidence of the indicator, whereas *Partially Demonstrated* indicated relevant but incomplete or inconsistent evidence. *Not Demonstrated* was assigned only when the task provided an adequate opportunity to demonstrate the indicator but no relevant evidence was identified. *Not Elicited* was used when the task or available data did not provide sufficient evidence to evaluate the indicator.

Semi-structured Interviews

Semi-structured interviews were conducted after the algebraic thinking test to obtain a more detailed account of the participants' reasoning processes. The interviews were intended to clarify how the participants interpreted the problem information, understood and used variables, constructed algebraic models, selected solution procedures, and explained the relationships between successive steps. The interviews also enabled the researcher to examine reasoning that may not have been explicitly represented in the participants' written work.

The interview questions were organized around several aspects of algebraic thinking, including symbolic interpretation, mathematical modeling, solution strategies, and justification of solution steps. Follow-up questions were used when necessary to clarify participants' explanations or explore the reasoning underlying particular written responses. Examples of the main interview prompts are presented in Table 3.

Table 3. Interview guide

Aspect	Focus of Inquiry	Example Question
Interpretation of variables	Understanding the meaning and role of symbols or variables	"What does the variable (x) represent in this problem?"
Mathematical modeling	Transforming contextual information into algebraic representation	"Can you explain how you converted the information in the problem into an algebraic expression?"
Solution strategy	Selecting and considering procedures for solving the problem	"How did you decide on this method of solving the problem?"
Alternative strategy	Exploring whether another valid method or representation can be used	"Can you think of another way to solve the same problem? Please explain it."
Analytical reasoning	Explaining algebraic operations and successive solution steps	"Why did you perform this operation at this stage?"
Organization and interpretation	Explaining the sequence of reasoning and meaning of the final result	"What does your final answer mean in relation to the original problem?"

The interview data were interpreted together with the written test responses rather than as an independent measure of achievement. This complementary use of the two data sources enabled the analysis to distinguish between reasoning that was explicitly recorded in writing and reasoning that became evident only through the participants' verbal explanations.

Data Analysis

The data were analyzed descriptively and qualitatively to characterize the algebraic thinking processes demonstrated by the three selected participants. The analysis focused on evidence obtained from the participants' written solutions and interview explanations, while the VAK questionnaire results were used to identify their learning-style preferences. Data analysis followed three interrelated stages: data reduction, data presentation, and conclusion drawing.

Data Reduction

Data reduction involved selecting, organizing, and coding information relevant to the research questions. The participants' written responses to each algebraic problem were first examined to identify evidence corresponding to the six algebraic thinking indicators: generalization, abstraction, modeling, dynamic thinking, analytical thinking, and organization. The interview data were then examined to clarify, elaborate on, or confirm reasoning that was not fully expressed in the written solutions.

For each participant and each problem, the evidence was compared with the operational definitions and observable evidence specified in Table 2. Each indicator was subsequently classified as Demonstrated (D), Partially Demonstrated (PD), Not Demonstrated (ND), or Not Elicited (NE). An indicator was coded as *Demonstrated* when clear and consistent evidence was identified in the written response, interview explanation, or both. *Partially Demonstrated* was assigned when relevant evidence was present but incomplete or inconsistent. *Not Demonstrated* was used only when the task provided an adequate opportunity to demonstrate the indicator but the participant showed no relevant evidence. *Not Elicited* was assigned when the task or available data did not provide sufficient opportunity to evaluate the indicator.

Importantly, the completeness of a written response was not treated as direct evidence of all forms of algebraic thinking. For example, failure to explicitly write what was known or asked in a problem was not automatically interpreted as a failure in generalization or abstraction. Instead, coding decisions were based on the specific cognitive evidence defined for each algebraic thinking indicator

Data presentation

The reduced data were organized through both within-case and cross-case analysis. In the within-case analysis, each participant—HFF, AFA, and SSSP—was examined individually to describe how the participant interpreted variables, constructed algebraic models, performed algebraic operations, organized solution steps, and explained the reasoning underlying the written response. Relevant excerpts from written work and interviews were used to support the interpretation of each case.

The cross-case analysis was subsequently conducted to identify similarities and differences among the three participants. Evidence from the visual, auditory, and kinesthetic cases was compared across the six algebraic thinking indicators. The comparison emphasized differences in the ways the participants represented, processed, organized, and communicated their algebraic reasoning rather than assuming that the observed characteristics represented all students with the same learning-style preference. The results were presented through descriptive narratives, excerpts from interviews, figures of students' written work, and a comparative coding matrix.

Conclusion Drawing

Conclusions were drawn by identifying recurring patterns and meaningful differences within and across the three cases. Interpretations were based on the convergence of evidence from the algebraic thinking test and the interviews. When a participant's written response did not explicitly reveal a reasoning process, the interview data were used to determine whether the reasoning could be supported verbally. Conversely, verbal explanations were interpreted in relation to the participant's written work to avoid drawing conclusions from isolated statements.

The final interpretation focused on describing the algebraic thinking characteristics demonstrated by each participant and comparing the patterns observed across the three learning-style preferences. Because the study involved one purposively selected participant from each VAK category, the conclusions were limited to the cases examined and were not intended to establish causal relationships or statistical generalizations regarding the effects of learning styles on students' algebraic thinking.

RESULTS

Participant Identification and Selection

At the initial stage of the study, 30 seventh-grade students completed the VAK learning-style questionnaire. The questionnaire results indicated that six students showed a predominantly visual preference, 14 showed an auditory preference, seven showed a kinesthetic preference, and three demonstrated a combined visual-auditory preference. The distribution of students' learning-style preferences is presented in Table 4.

Table 4. Distribution of students' learning-style preferences

No.	Learning-Style Preferences	Number of items
1	Visual	6
2	Auditory	14

3	Kinesthetic	7
4	Visual-Auditory	3
Total		**30**

The students also completed the algebraic thinking test. Based on the questionnaire results, preliminary mathematical performance, and the participants' ability and willingness to explain their reasoning during the interview, three students were purposively selected for in-depth analysis. HFF represented the visual learning-style preference, AFA represented the auditory preference, and SSSP represented the kinesthetic preference, as shown in Table 5.

Table 5. Selected participants

Participant	Learning-Style Preferences
HFF	Visual
AFA	Auditory
SSSP	Kinesthetic

The written solutions and interview explanations of these three participants were subsequently analyzed using the operational indicators of algebraic thinking presented in Table 2. The analysis was first conducted within each case and was then followed by a cross-case comparison.

Within-Case Analysis

HFF: Visual Learning-Style Preference

HFF's written responses showed that the participant was able to construct appropriate algebraic representations and carry out the required algebraic operations for both problems. Although HFF did not explicitly write all of the information given in the problems or restate what was being asked, the written solution remained sufficiently coherent to trace the main reasoning process. During the interview, HFF was also able to verbally identify the relevant information and explain the objectives of both problems.

As shown in Figure 1, HFF represented the contextual information algebraically and proceeded to simplify the expressions and substitute the given value of the variable. These actions provided evidence of abstraction, modeling, and analytical thinking. HFF used the variable consistently to represent the relevant quantity, translated the relationships in the problems into algebraic expressions, and performed the required operations appropriately.

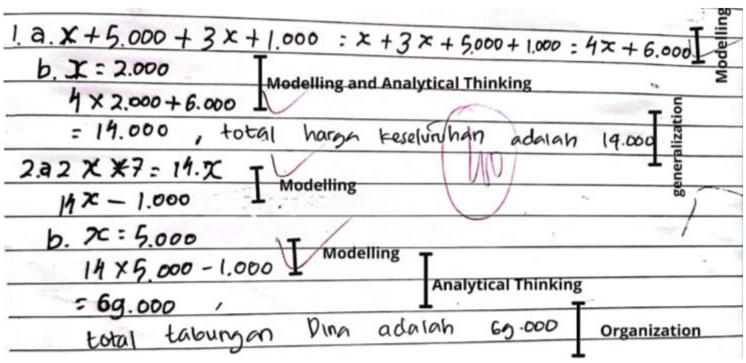

Figure 1. HFF's written responses to Problems 1 and 2

The interview data supported the interpretation of HFF's written work. When asked to identify the information provided in the problems, HFF was able to explain the relevant quantities verbally. HFF was also able to state what each problem required and to describe the reasoning used to construct the algebraic model. Thus, the absence of explicitly written "known" and "asked" components was not interpreted as evidence of failure in generalization or abstraction because these written conventions are not equivalent to the corresponding algebraic-thinking constructs.

For abstraction, HFF demonstrated an appropriate understanding and use of the variable in the problem context. For modeling, HFF translated the quantitative relationships into algebraic form appropriately. Analytical thinking was also demonstrated through the simplification of algebraic expressions and substitution of the specified variable values. In terms of organization, the principal mathematical steps could be followed logically from the written work and were further clarified during the interview. Therefore, organization was coded as demonstrated.

However, the available test and interview evidence did not provide a sufficiently explicit basis for determining whether HFF generalized a relationship into a broader mathematical rule. Similarly, no clear evidence showed that HFF developed, compared, or applied an alternative solution strategy. Consequently, generalization and dynamic thinking were classified as not elicited rather than not demonstrated.

AFA: Auditory Learning-Style Preference

AFA's written responses revealed a somewhat different pattern. In Problem 1, AFA did not explicitly record the initial information from the problem, whereas some relevant information was written in Problem 2. AFA also did not explicitly state what was being asked in either problem. Nevertheless, during the interview, AFA was able to explain the relevant information and the objectives of both tasks verbally.

AFA's written response to Problem 1 is presented in Figure 2. The solution showed that AFA was able to translate the contextual relationships into an algebraic representation and carry out the required operations.

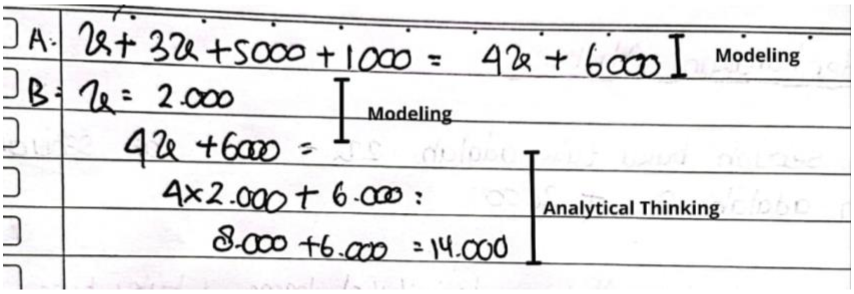

Figure 2. AFA's written response to Problem 1

AFA's response to Problem 2 showed a similar pattern. The participant constructed an algebraic model, simplified the expression, and substituted the specified value to determine the result. The written reasoning was mathematically productive, although some explanatory components were omitted.

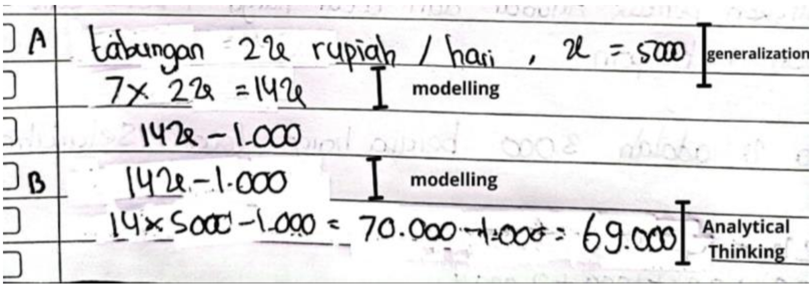

Figure 3. AFA's response to Problem 2

The interview data provided additional evidence that AFA understood the information and purpose of the problems despite not consistently expressing these components in writing. AFA was able to explain how the contextual information was transformed into algebraic form and how the subsequent calculations were carried out. These findings supported coding abstraction, modeling, and analytical thinking as demonstrated.

AFA's organization of the written solutions was coded as partially demonstrated. The central mathematical operations were presented in an understandable sequence, but the written responses were less complete in communicating the overall solution process. In particular, some initial information was omitted, and the solutions did not conclude with an explicit statement interpreting the final result in relation to the original problem. The interview compensated for some of these omissions by showing that AFA could explain the reasoning verbally.

As in HFF's case, the available evidence did not sufficiently elicit generalization as the formulation of a broader algebraic rule. Likewise, although AFA followed a valid strategy, the data did not show that the participant generated, compared, or applied an alternative strategy. Generalization and dynamic thinking were therefore coded as not elicited.

SSSP: Kinesthetic Learning-Style Preference

SSSP produced the most explicitly organized written responses among the three participants. The written work included the relevant problem information, the algebraic representation, the calculation process, and the interpretation of the final result. SSSP was also able to explain these stages verbally during the interview.

Figure 4 presents SSSP's response to Problem 1. The written solution showed a clear progression from interpreting the quantities in the problem to constructing the algebraic expression, simplifying it, substituting the specified value, and determining the final result.

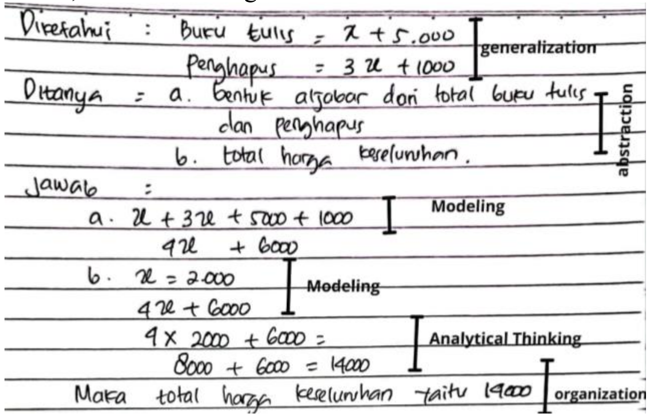

Figure 4. SSSP's written response to Problem 1

A similarly explicit sequence was observed in SSSP's solution to Problem 2. As presented in Figure 5, the participant transformed the contextual information into an algebraic model, simplified the expression, substituted the given value, and stated the result in relation to the problem context.

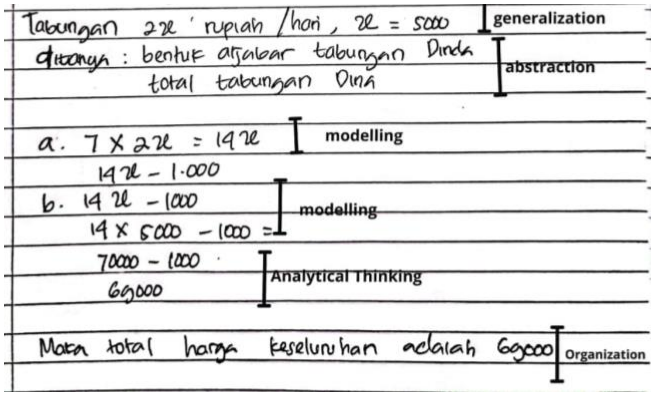

Figure 5. SSSP's written response to Problem 2

The combined written and interview evidence indicated that SSSP demonstrated abstraction by appropriately interpreting and using the variable, modeling by transforming the quantitative relationships into algebraic expressions, and analytical thinking by correctly manipulating and evaluating the expressions. Organization was also demonstrated because the solution process was communicated in a coherent and traceable sequence from the initial representation to the final interpretation.

Nevertheless, the completeness of SSSP's written work was not treated as evidence that all six algebraic-thinking indicators were necessarily demonstrated. The available tasks did not require the participant to formulate a broader general rule beyond the specific situations provided, and no sufficiently explicit evidence indicated that SSSP generated or compared alternative solution strategies. Therefore, generalization and dynamic thinking were classified as not elicited.

Cross-Case Analysis

The cross-case analysis revealed substantial similarities in the core algebraic processes demonstrated by HFF, AFA, and SSSP. All three participants showed evidence of abstraction, modeling, and analytical thinking. Each participant used the variable meaningfully within the problem context, transformed contextual relationships into algebraic form, and carried out the necessary algebraic operations to obtain a solution.

The clearest difference among the three cases concerned the organization and communication of the solution process. HFF presented a mathematically coherent sequence even though some conventional written components, such as explicitly stating the information given and the question asked, were omitted. AFA also demonstrated appropriate algebraic reasoning, but the written solutions were less complete and did not provide explicit concluding statements. In contrast, SSSP communicated the solution process most explicitly, presenting the relevant information, algebraic representation, calculation steps, and final interpretation in a clearly traceable sequence.

The cross-case coding results are summarized in Table 6.

Table 6. Cross-Case Coding of Algebraic Thinking Indicators

Algebraic Thinking Indicator	HFF - Visual	AFA - Auditory	SSSP - Kinesthetic
Generalization	NE	NE	NE
Abstraction	D	D	D
Modeling	D	D	D
Dynamic Thinking	NE	NE	NE
Analytic Thinking	D	D	D
Organization	D	PD	D

Note. D = Demonstrated; PD = Partially Demonstrated; NE = Not Elicited.

The comparison indicates that the three cases did not primarily differ in their ability to construct algebraic models or perform algebraic operations. Instead, the most visible difference occurred in how explicitly they organized and communicated their reasoning in written form. SSSP produced the most complete written representation of the solution process, whereas HFF and particularly AFA relied to a greater extent on verbal explanations to clarify information that was not fully expressed in writing.

No cross-case conclusion was drawn for generalization or dynamic thinking because the available tasks and interview evidence did not provide sufficient opportunities to assess these indicators consistently across the three participants. This distinction is important because the absence of observable evidence under such conditions should not be interpreted as an inability to generalize or use alternative strategies.

Overall, the findings show that all three participants demonstrated core algebraic processes related to symbolic interpretation, mathematical modeling, and analytical manipulation, while differences were more apparent in the organization and communication of their solution processes. These findings describe the characteristics of the three cases examined and are not intended to establish that particular learning-style preferences determine students' algebraic-thinking ability.

DISCUSSION

The findings showed that the three participants demonstrated substantial similarities in several core aspects of algebraic *thinking*. HFF, AFA, and SSSP all demonstrated abstraction, modeling, and analytical thinking when solving the contextual algebraic problems. Each participant was able to use variables meaningfully, transform quantitative relationships into algebraic representations, simplify algebraic expressions, and substitute the given values appropriately. These findings support the view that algebraic thinking involves more than performing symbolic manipulation; it also requires students to interpret quantities, establish relationships among them, and represent those relationships algebraically (Sibgatullin et al., 2022). The ability of the three participants to construct algebraic representations from contextual information also reflects the central role of symbolic representation and quantitative reasoning in algebraic problem solving (Kusuma et al., 2024).

The cross-case analysis further indicated that the most visible difference among the three participants was not in their ability to construct mathematical models or perform algebraic operations, but in how they organized and communicated their reasoning. HFF, who demonstrated a visual learning-style preference, produced mathematically coherent solutions despite omitting some conventional written components, such as explicitly stating the given information and the question being asked. These omissions did not prevent HFF from explaining the relevant information and reasoning during the interview. This finding suggests that the completeness of a written response should be distinguished from the underlying algebraic reasoning demonstrated by a student. Previous studies have similarly shown that students may display different characteristics in representing and communicating their mathematical reasoning even when they are able to solve the underlying problem successfully (Rahmawati et al., 2019; Yusrina et al., 2023).

AFA, who represented the auditory learning-style preference, also demonstrated abstraction, modeling, and analytical thinking. However, AFA's written solutions contained fewer explicit explanatory components and did not consistently include concluding statements. During the interview, AFA was nevertheless able to verbally explain the information contained in the problems, the purpose of the tasks, and the procedures used to obtain the solutions. Thus, the combination of written responses and interview explanations provided a more complete account of AFA's algebraic reasoning than the written work alone. This pattern is broadly compatible with previous findings showing that students with different learning preferences may differ in how they express their understanding of mathematical problems (Sulisawati et al., 2019). However, the present study does not establish that AFA's verbal–written pattern was caused by an auditory learning-style preference; rather, it describes the pattern observed in this particular case.

Among the three participants, SSSP, who demonstrated a kinesthetic learning-style preference, produced the most explicitly organized written solutions. The participant systematically recorded relevant information, developed algebraic representations, carried out calculations, and interpreted the final results. This organization made the entire problem-solving process easier to trace from the initial representation to the final answer. Previous research has reported variation in students' algebraic problem-solving processes when examined in relation to individual learning or cognitive characteristics (Agustina et al., 2024; Rosida & Masduki, 2023). Nevertheless, SSSP's more complete written organization should not be interpreted as evidence that students with kinesthetic preferences generally possess stronger algebraic-thinking ability. In the present study, the observation applies specifically to SSSP and primarily concerns the explicit organization and communication of the solution rather than superiority in the underlying algebraic processes.

An important methodological implication of these findings concerns the distinction between mathematical reasoning and the format in which that reasoning is communicated. In the original interpretation of the data, failure to write "what is known" or "what is asked" could have been treated as an indication that particular algebraic-thinking indicators were not achieved. The revised analysis shows that such written conventions are not equivalent to generalization or abstraction. Algebraic thinking should instead be interpreted through evidence that corresponds directly to the underlying construct, such as interpreting variables, representing quantitative relationships, constructing algebraic models, and performing logically connected algebraic operations. This construct-based interpretation is consistent with the broader understanding of algebraic thinking as a reasoning process involving representation, generalization, and relationships among quantities rather than merely the procedural completion of a prescribed written format (Sibgatullin et al., 2022).

The complementary use of written tests and interviews was therefore important in interpreting the three cases. Written solutions revealed how participants represented and organized their mathematical work, whereas the interviews clarified reasoning that was not always explicitly recorded. For HFF and AFA in particular, some aspects of problem comprehension and solution reasoning became clearer through verbal explanation. This reinforces the importance of examining students' algebraic thinking through their reasoning processes rather than evaluating competence solely from final answers or the completeness of written presentation. An analysis of students' problem-solving processes can provide information about how mathematical knowledge is constructed and applied during algebraic tasks (Kusuma et al., 2024).

The findings also revealed a limitation of the algebraic thinking test used in this study. Although the theoretical framework included six indicators—generalization, abstraction, modeling, dynamic thinking, analytical thinking, and organization—the two contextual problems provided stronger evidence for abstraction, modeling, analytical thinking, and organization than for generalization and dynamic thinking. The tasks did not explicitly require students to formulate generalized rules beyond the particular situations provided, nor did they systematically require students to generate or compare alternative solution strategies. Consequently, generalization and dynamic thinking were classified as *not elicited*for all three participants rather than *not demonstrated*. This distinction prevents the absence of observable evidence from being interpreted as an absence of the corresponding ability. Given that generalization is considered an important component of algebraic thinking (Sibgatullin et al., 2022), future assessments should include tasks specifically designed to elicit generalized relationships and multiple solution strategies.

Taken together, the cross-case findings provide a more cautious interpretation of the relationship between VAK learning-style preferences and algebraic thinking than a causal explanation would allow. The three participants showed comparable evidence in abstraction, modeling, and analytical thinking, whereas their most apparent difference concerned the explicit organization and communication of their solutions. Previous studies have reported differences in mathematical problem-solving characteristics in relation to learning or cognitive preferences (Rosida & Masduki, 2023; Sulisawati et al., 2019). The present findings add to this discussion by suggesting that, in these three cases, differences associated with VAK classifications were more visible in the manner in which reasoning was expressed than in the core algebraic processes successfully demonstrated. Because only one participant represented each learning-style preference, these patterns should be understood as case-specific characteristics rather than general characteristics of visual, auditory, or kinesthetic learners.

From a pedagogical perspective, the findings suggest that teachers should consider multiple forms of evidence when examining students' algebraic thinking. A concise written response does not necessarily indicate limited conceptual understanding when the student can provide coherent reasoning through further explanation. Conversely, a well-organized written solution provides valuable evidence because it makes the relationships among representations, operations, and conclusions visible. Algebra instruction can therefore provide opportunities for students to communicate reasoning through written representations, verbal explanations, and explicit justification of algebraic relationships. Such an approach is consistent with the view that effective algebra learning should engage students in meaningful problem solving and support the development of conceptual as well as procedural understanding (Jamil et al., 2025; Rahmawati and Neviyarni, 2026).

CONCLUSION

This study aimed to describe students' algebraic thinking processes in solving algebraic problems across visual, auditory, and kinesthetic learning-style preferences and to identify similarities and differences among the three cases. The findings showed that HFF, AFA, and SSSP all demonstrated abstraction, modeling, and analytical thinking by appropriately interpreting variables, constructing algebraic representations from contextual information, and performing the required algebraic operations. The most apparent difference among the cases concerned the organization and communication of reasoning rather than the core algebraic processes demonstrated. HFF presented a coherent solution process despite omitting some conventional written components, AFA relied more extensively on verbal explanations to clarify aspects that were not fully expressed in writing, and SSSP produced the most explicitly organized and traceable written solutions. These patterns indicate that students' algebraic thinking should be examined through multiple forms of evidence, including both written work and verbal explanation, rather than inferred solely from the completeness of written responses or final answers. The study did not establish that VAK learning-style preferences determine algebraic-thinking ability; instead, it identified case-specific differences in how the three participants represented, organized, and communicated their reasoning. In addition, generalization and dynamic thinking could not be evaluated adequately because the tasks did not sufficiently elicit the formulation of generalized relationships or the use of alternative solution strategies. Future studies should therefore employ algebraic tasks specifically designed to elicit these processes, involve a broader range of participants and problem types, and further examine how different forms of mathematical representation and communication are associated with students' algebraic reasoning. In instructional practice, the findings support the use of varied opportunities for students to express algebraic reasoning through symbolic representations, written explanations, verbal justification, and explicit interpretation of solutions.

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