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Analysis of Students' Visual, Symbolic, and Verbal Representations as Indicators of Mathematical Representation Ability in a Quadratic Function Test

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Abstract: This study aims to analyze students' visual, symbolic, and verbal representations as indicators of mathematical representation ability in solving a quadratic function test. The study employed a descriptive quantitative approach with a cross-sectional design. The research subjects consisted of 127 tenth-grade students from three senior high schools who had studied quadratic functions. Data were collected through an essay test consisting of six items to measure the indicators of visual, symbolic, and verbal representation. The data were analyzed using descriptive statistics through answer scoring, score grouping based on representation indicators, and conversion into percentage form. The results showed that students' mathematical representation ability was still relatively low and had not developed evenly, with visual representation achieving the highest percentage at 36.68%, followed by verbal representation at 13.92%, while symbolic representation was the lowest indicator at 10.02%. The findings also showed that students already possessed basic abilities in familiar problems, but still experienced difficulties when they had to interpret graphs, understand function notation, connect different representations, and relate quadratic functions to other topics such as function transformations. These difficulties indicate that students' understanding still tends to be partial and procedural, so that conceptual connections among representations have not been formed as a whole. Thus, the teaching of quadratic functions needs to be designed in a more balanced way by emphasizing conceptual understanding, the interconnection among representations, and the development of students' mathematical argumentation.

Keywords: Mathematical Representation, Quadratic Functions, Symbolic, Verbal, Visual

Introduction

Mathematics is a discipline that plays an important role in developing students' logical thinking, problem-solving ability, and critical thinking skills. One of the main aspects of mathematics learning is the ability to understand and use various forms of mathematical representation. Mathematical representation is very important because it enables students to express, interpret, and solve mathematical problems in various ways. Pedersen et al. (2021) state that representation is an important part of mathematical activity, both for learners and for mathematicians, because understanding mathematical concepts depends greatly on an individual's ability to handle various forms of representation and to move from one form of representation to another. In line with this, Ghani (2023) emphasizes that mathematical representation is one of the main goals of mathematics learning because this ability is closely related to students' communication and problem-solving skills. In this context, mathematical representation can be understood as various ways of presenting mathematical ideas, which in this study are focused on visual, symbolic, and verbal representations as indicators of students' mathematical representation ability. Each of these forms of representation has a different function in supporting understanding and the process of solving mathematical problems.

Visual representation involves the use of graphs, diagrams, and other pictorial elements that help students understand mathematical relationships and structures. This form of representation allows students to see patterns and relationships that may not be immediately visible in symbolic or verbal form. For example, in learning quadratic functions, students can analyze the shape and properties of a parabola to understand concepts such as the roots of an equation, the vertex, and graph symmetry. Research shows that visual representation can improve students' ability to understand complex mathematical concepts, especially when they experience difficulties in abstract thinking (Ünal et al., 2023).

Meanwhile, symbolic representation is a system of mathematical notation that includes numbers, variables, and equations. This representation is the most commonly used form in mathematical problem solving and is considered the foundation for advanced mathematical reasoning. The ability to manipulate symbols effectively is very important in solving quadratic function problems because it enables students to construct equations, factor expressions, and apply mathematical operations systematically. However, many students experience difficulties in moving from visual representation to symbolic representation. This is shown by errors in calculation and in the use of mathematical formulas among students who are less capable in symbolic representation (Novitasari et al., 2021). In addition, students tend to use available formulas rather than understand the mathematical concepts in depth, which indicates obstacles in the transition from visual to symbolic understanding (Sri Wahyuning & Nida Sri Utami, 2024). This difficulty is also seen in students' challenges in moving from arithmetic thinking to a more abstract algebraic perspective, which often hinders them in using mathematical models symbolically (Ünal et al., 2023).

In addition, verbal representation includes written and oral explanations of mathematical concepts. This representation involves the ability to describe mathematical concepts in words, interpret problem statements, and communicate the thinking process in solving problems. Verbal representation plays an important role in supporting conceptual understanding because it allows students to articulate their thoughts and provide justification for the solutions they produce. However, research shows that many students have low verbal representation ability, as indicated by difficulties in writing problem-solving steps clearly (Septiani et al., 2020). This difficulty often occurs because students are not yet accustomed to communicating their mathematical ideas in written or oral form, so they experience obstacles in explaining the relationship between symbolic and verbal concepts (Rum & Juandi, 2023). This challenge highlights the need for a learning approach that integrates verbal explanation with symbolic and visual representation to improve students' mathematical competence as a whole.

Mathematical representation has an important role in learning quadratic functions, but studies show that students often experience an imbalance in their ability to use various forms of representation. Many students rely too heavily on one form of representation while experiencing difficulties in using others. For instance, some students may excel in visual representation but experience difficulty in algebraic symbolic manipulation, while others may perform symbolic calculations well but have difficulty explaining their thinking verbally. Samsuddin & Retnawati (2018) emphasize that mathematical representation functions as a bridge connecting abstract concepts with real contexts, but students face challenges in using it in a balanced way. This is in line with the findings of Li et al. (2018), which show that symbolic skills are more dominant in influencing mathematical performance than non-symbolic representation, which may explain why many students are more comfortable with symbolic calculations but have difficulty understanding concepts through other representations. In addition, Novitasari et al. (2021) found that although students can use various types of representation in solving problems, they often experience errors in symbolic manipulation and the use of formulas.

These findings indicate that the problem of mathematical representation lies not only in the ability to use one particular form of representation, but also in the ability to coordinate visual, symbolic, and verbal representations in a balanced way. In the context of quadratic functions, this issue becomes important because the topic requires students to read and interpret graphs, use algebraic forms, and explain the meaning of concepts in written and oral form. Nevertheless, studies that specifically portray these three forms of representation as indicators of students' mathematical representation ability in the context of a quadratic function test still need to be further clarified.

These challenges in mathematical representation have significant implications for teaching and learning. Traditional learning approaches often place greater emphasis on symbolic manipulation, while visual and verbal representations receive less attention, as highlighted by Boaler et al. (2016), who show that visual representation is often neglected in traditional curricula. As a result, students tend to develop procedural skills without a deep conceptual understanding of the mathematical structures underlying quadratic functions. To address this problem, Lee et al. (2018) highlight the importance of clear representational structure to help students translate information from text form into symbolic form, thereby improving their flexibility in solving problems. In addition, Post & Prediger (2024) emphasize that merely having multiple representations is not enough; effective teacher interaction and instructional design are needed to help students connect and understand various forms of representation more deeply. Therefore, a more comprehensive understanding of students' representational profiles is needed so that teachers can design instruction that not only emphasizes symbolic procedures but also develops conceptual connections among representations.

Quadratic functions are one of the fundamental topics in secondary school mathematics that also use various representations in the learning process. Quadratic functions are generally expressed in the form $f(x) = ax^2 + bx + c$, where a, b, and c are constants, and their graph is a parabola. Understanding quadratic functions includes analyzing their algebraic properties, interpreting their graphs, and being able to explain related concepts verbally. The ability to move from one representation to another is very important for mastering quadratic functions because different types of problems may require different forms of representation to be solved effectively.

Based on the description above, it can be understood that students' mathematical representation ability in the topic of quadratic functions needs to be examined through three main indicators, namely visual, symbolic, and verbal representation. Identifying students' ability on these three indicators is important to provide a clearer picture of their strengths and weaknesses in understanding quadratic functions. Therefore, this study aims to analyze students' visual, symbolic, and verbal representations as indicators of mathematical representation ability in solving a quadratic function test. The results of this study are expected to provide an overview of students' mathematical representation ability profiles and to serve as a basis for the development of more balanced and meaningful instruction.

Method

This study employed a descriptive quantitative approach aimed at describing students' mathematical representation ability in solving quadratic function problems. The research design used was cross-sectional, meaning that data were collected only once from the research subjects within a particular period without repeated observations. This design was chosen because the study focused on capturing students' representation ability at the time the test was administered, rather than examining the development of ability over time. The use of a cross-sectional design was considered appropriate for efficiently describing the characteristics of a population at a single point in time (Lovett & Johnson, 2012; Wang & Cheng, 2020). The study was conducted in three senior high schools located in the same city. The selection of schools within one area was intended to maintain similarity in curriculum context and learning environment. The research was carried out in the even semester of the 2023/2024 academic year, namely from January to June 2024.

The research subjects were all tenth-grade students who had studied quadratic functions in the three schools. The research sample consisted of 127 students and was selected using purposive sampling. This technique was used because the sample selection was based on certain considerations in accordance with the research objectives, namely that the students had received instruction on quadratic functions, came from schools with a similar curriculum, and were willing to take the test administered. Purposive sampling was used to select participants considered most capable of providing relevant data in accordance with the research objectives (Campbell et al., 2020).

The research instrument was an essay test of mathematical representation ability on the topic of quadratic functions. The test consisted of six items constructed based on three indicators of mathematical representation, namely visual, symbolic, and verbal. Visual representation was measured through questions 1 and 2, symbolic representation was measured through questions 3 and 5, while verbal representation was measured through questions 4 and 6.

For the visual indicator, students were asked to draw the graph of a quadratic function, determine the vertex, and show the result of a graph transformation. For the symbolic indicator, students were asked to construct the form of a quadratic function from the information presented and to use a quadratic function model to solve problems. For the verbal indicator, students were asked to determine which functions were quadratic functions along with the reasons, explain the characteristics of the function, and write the solution steps and conclusions in written form. Each test item was assessed using an analytic scoring rubric based on the expected answer components for each question. The maximum score for each item differed, namely 8 for question 1, 4 for question 2, 13 for question 3, 14 for question 4, 13 for question 5, and 8 for question 6. These differences in maximum scores were adjusted to the level of complexity of the response demands for each question.

Before being used in the study, the instrument was first validated by three experts in mathematics education. The validation was conducted to assess the appropriateness of the items with the quadratic function material, the indicators of mathematical representation ability, language clarity, image readability, answer key clarity, and scoring fairness. Content validity assessment through expert judgment is an important step in instrument development because it helps ensure that the test items truly represent the construct being measured (Almanasreh, Moles, & Chen, 2019). Based on the validation results, all test items were declared suitable for use after revisions were made in accordance with the validators' suggestions. After validation, the instrument was first piloted to ensure that the test could be properly used in the research data collection. Subsequently, the test was administered to the students who became the research sample. The students' answers were then collected, examined, and scored based on the rubric that had been prepared.

The research data were obtained through a written test specifically designed to measure students' mathematical representation ability on the visual, symbolic, and verbal indicators in the context of quadratic functions. The research data consisted of students' answer scores on each test item according to the representation indicator being measured. In addition, students' answers were also examined to identify the forms of errors that appeared in each representation indicator.

Data analysis was carried out using descriptive statistics. The analysis stage began with scoring each student's answer according to the scoring rubric. The scores for each item were then summed based on the representation indicators, namely visual, symbolic, and verbal. Furthermore, the scores for each indicator were converted into percentages so that achievement across indicators could be compared more clearly. The analysis results were used to describe the tendency of students' mathematical representation ability on each indicator, while also identifying the parts that still constituted students' weaknesses in solving quadratic function problems.

Results and Discussion

The analysis results show that students' mathematical representation ability on the topic of quadratic functions is still relatively low and has not developed evenly across each indicator. Based on the score recap of 127 students, the total score obtained by the students was 1,279 out of a maximum score of 7,620, so the overall achievement reached only 16.78% of the maximum score. When viewed by indicator, visual representation achieved the highest percentage, namely 36.68%, followed by verbal representation at 13.92%, while symbolic representation was the indicator with the lowest achievement, namely 10.02%. These findings indicate that students find it relatively easier to express mathematical ideas in simple visual form, but they still experience difficulties when they have to construct symbolic models or explain mathematical reasoning in writing. The tendency that students' representation ability does not develop evenly across each aspect is consistent with the findings of Utami, Mardiyana, & Pramudya (2021), which show that students tend to have greater mastery of visual representation than other aspects, while the verbal aspect is the weakest part. Meanwhile, the low achievement in the symbolic aspect can be understood through the findings of Saifiyah & Retnawati (2019), which show that students often experience difficulties in understanding and using mathematical symbols, make calculation errors, and are unable to continue the solution to the final stage.

When analyzed by item, it appears that question number 1 obtained the highest percentage of achievement, namely 53.35%, whereas question number 2 obtained the lowest percentage, namely only 3.35%. Question number 3 obtained 9.39%, question number 4 obtained 14.51%, question number 5 obtained 10.66%, and question number 6 obtained 12.89%. The low achievement in most items indicates that many students have not yet been able to complete representation tasks fully, especially when the questions require a transition from one form of representation to another or require more structured written explanations. This finding is consistent with Jäder & Johansson (2025), who state that mathematical problems often require students to construct new representations and that conceptual challenges in problem solving may arise when students have to navigate relationships among representations or face unfamiliar situations. In line with this, Li, Shen, Jiao, & Cai (2022) also show that many students still experience difficulties connecting various representations, even when they have mastered each representation separately. The score recap also shows that zero scores were highly dominant on several items, especially question number 2, followed by question number 6, question number 4, and question number 3. This pattern shows that students' difficulties lie not only in the final result, but also in the process of constructing representations that are appropriate to the demands of the questions.

On the visual indicator, students' achievement was relatively better than on the other indicators, but the quality of the representations produced still showed many weaknesses. In question number 1, some students were already able to determine several coordinate points from the given function and then plot those points on the Cartesian plane. However, the resulting graph often did not form a parabola accurately. Some students also did not explicitly write the vertex, did not explain the type of vertex, or did not indicate whether the graph opened upward or downward. This shows that students already have an initial understanding of the basic elements of quadratic functions but have not yet been fully able to integrate this information into an accurate visual form.

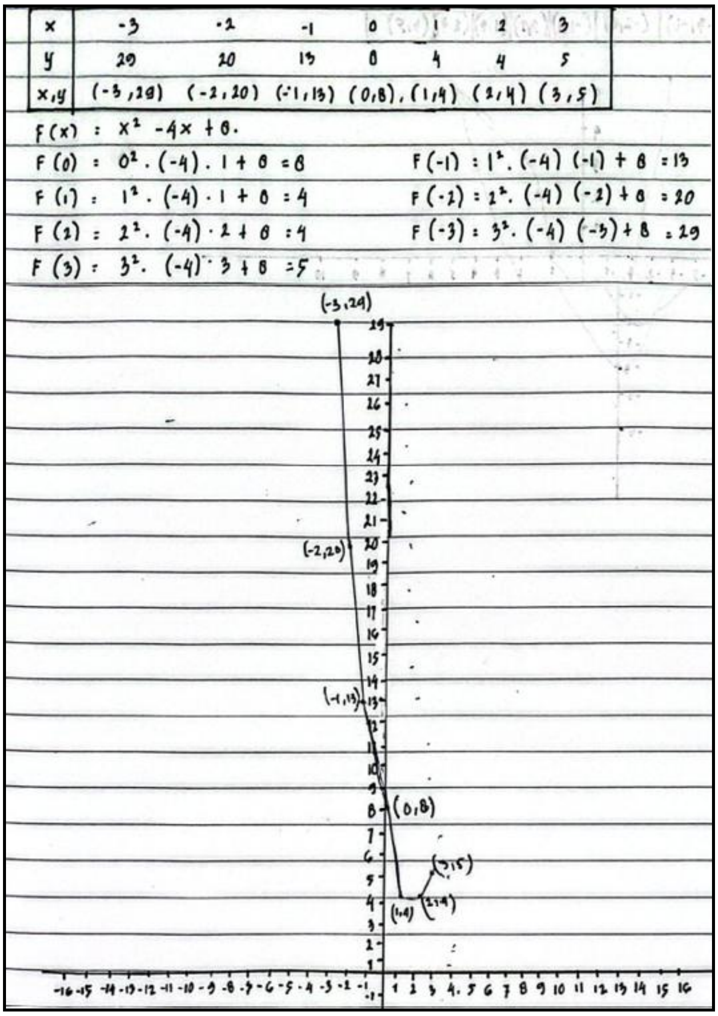

Figure 1. Example of a student's answer for the visual indicator

This figure shows one student's answer to question number 1. The student attempted to determine several point pairs from the quadratic function and plot them on the Cartesian plane. However, the resulting graph did not yet accurately represent a parabola, and the vertex was also not explicitly stated. This finding is in line with the study by Syarifuddin & Sari (2021), which shows that in drawing function graphs, students often rely on plotting without first identifying the characteristics of the function being graphed. This indicates that students do not yet understand the property of parabola symmetry, particularly that the x-coordinate of the vertex lies at the midpoint between two x-coordinates that have the same y-coordinate. As a result, students are not yet able to estimate the position of the vertex accurately. In addition, the graph shape, which still resembles a broken line, indicates that students do not yet view a parabola as a smooth and symmetrical curve. This condition is also in line with the findings of Best & Bikner-Ahsbahs (2017), that students tend to construct graphs by plotting computed points and then connecting them with straight lines, and have not yet used the coordinate system appropriately as a reference space for graph representations of functions. Thus, students seem to have recognized several characteristics of the parabola but still understand them separately and have not yet been able to integrate them into a correct visual representation.

Difficulties in visual representation were clearly evident in question number 2. Many students did not interpret f(x – 1) as a horizontal shift of the quadratic function graph, but instead misinterpreted it through incorrect substitution, changed it into a linear function, or only wrote the original function form without producing the final graph. This shows that when students have to connect symbolic form with changes in the graph, they still experience conceptual obstacles. This finding is in line with previous research stating that students often experience difficulties in reading visual representations, assigning meaning to visual elements, moving between representations, and interpreting graphs accurately (Johar & Lubis, 2018; López & Pintó, 2017; Žakelj & Klančar, 2022). Thus, this study extends previous research by showing that these obstacles also appear in interpreting the form f(x – 1) in the context of quadratic function transformations.

On the symbolic representation indicator, the difference in students' difficulties was evident in questions 3 and 5. In question number 3, which was presented through a parabola graph, some students already showed an appropriate direction of solution by writing the general form $f(x) = ax^2 + bx + c$ and substituting points to obtain initial information, for example, the value of c, although they had not yet succeeded in determining the values of a and b completely. This shows that in visual problems, students are still able to capture mathematical information and begin translating it into algebraic form. In contrast, in question number 5, which was presented as a word problem, students' difficulties were more clearly visible. In item (a), students understood that "touching the ground" meant h(t) = 0, but they were unable to continue the solution. In item (b), students had not yet understood that the initial height was related to the function value when t = 0. In item (c), students had realized that what was being asked was related to an extreme value, but they had not yet been able to distinguish between the maximum value of t and the maximum value of h(t).

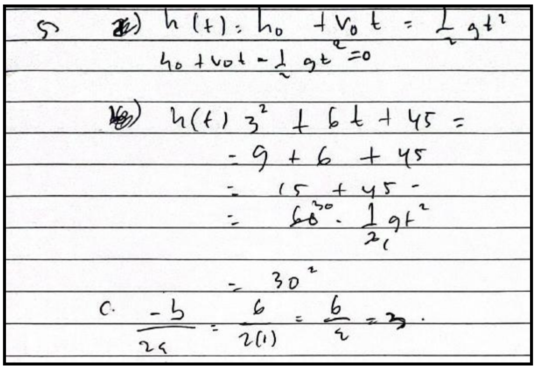

Figure 2. Example of a student's answer for the symbolic indicator

These findings show that difficulties in symbolic representation are not only related to algebraic manipulation, but also to the ability to interpret the meaning of the problem, especially when the problem is presented verbally. These findings are in line with previous studies showing that mathematical representation requires the ability to translate information among various forms, such as verbal, visual, and symbolic, and to connect them with appropriate mathematical meaning in problem solving (Johar & Lubis, 2018; Mainali, 2021; Santia, Purwanto, Sutawidjadja, Sudirman, & Subanji, 2019). Thus, this study extends previous research by showing that obstacles in symbolic representation tend to be more pronounced when problems are presented in verbal form rather than visual form.

On the verbal indicator, students' achievement was still low. This difficulty was evident in questions 4 and 6, which required students to explain reasons, write the characteristics of functions, and construct written conclusions. In question number 4, some students were already able to identify forms that were quadratic functions, but the reasons given were often still inaccurate or incomplete. The most dominant pattern was that students only wrote the answer they considered correct without elaborating on the characteristics of quadratic functions. In addition, some students were still mistaken in interpreting the condition for a quadratic function, for example, by assuming that the coefficients a and c must not be equal to zero, whereas the main condition is that the coefficient a must not be equal to zero. This finding shows that some students have generally recognized the form of quadratic functions but have not yet fully understood the characteristics of quadratic functions or explained the basis of the answers they provided.

The same difficulty was evident in question number 6. In this question, students were asked to compare the maximum values of two quadratic functions, determine which opinion was correct, and explain the steps used.

However, many students did not conclude who was correct, only wrote the maximum value of one function, equated the forms of the two functions, or gave the correct answer without adequate explanation. This pattern shows that students are often able to carry out part of the procedure but are not yet able to turn the calculation results into clear and complete mathematical arguments or draw conclusions from those calculation results.

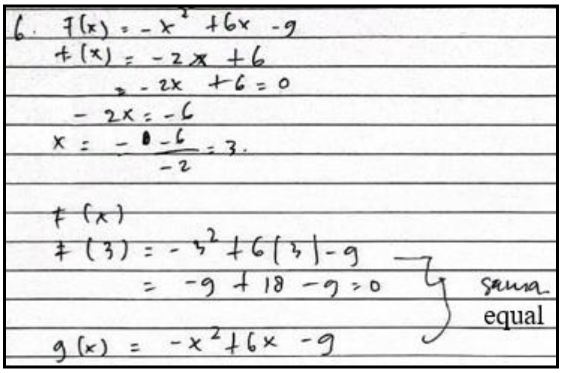

Figure 3. Example of a student's answer for the verbal indicator

This figure shows that the student did not use the graph representation of f(x) as required in the question. Instead, the student equated the algebraic form of f(x) with g(x), then calculated the maximum value procedurally. As a result, the student directly concluded that both functions had the same maximum value. This shows that students are not yet accustomed to determining the maximum value directly from the graph and tend to associate the maximum value with the procedure or formula for the maximum point of a quadratic function.

The results of this study extend previous findings on students' difficulties in mathematical representation. In the topic of quadratic functions, students have actually shown basic ability on problems presented directly and in familiar forms. However, when faced with problems that require further interpretation or transitions between representations, obstacles begin to appear more clearly. These difficulties indicate that students tend to interpret the components of quadratic functions separately in each representation, rather than as one fully connected concept. For example, students may be able to determine the vertex symbolically through a formula, but are not yet able to recognize or explain it in visual or verbal form. In visual representation, students tend only to plot points without relating them to the characteristics of quadratic functions, such as symmetry, the shape of the parabola, and the position of the vertex. In addition, limitations in connecting quadratic functions with other topics, such as function transformations, also create obstacles in understanding the information in the problem as a whole. These limitations in interpretation and in building connections among concepts ultimately affect verbal representation, so that students are not yet able to provide reasons, describe function characteristics, and construct mathematical conclusions clearly. Thus, the solution steps chosen by students do not yet appear to be fully based on a conceptual schema that has been formed as a whole, but rather on the habit of using procedures that they have previously learned.

Conclusion

This study shows that students' mathematical representation ability on the topic of quadratic functions is still relatively low and has not developed evenly across the visual, symbolic, and verbal indicators. Nevertheless, the findings also show that students already possess the basic ability to solve problems presented in a direct and familiar form. Difficulties become more apparent when students are faced with problems that require the interpretation of information, transitions between representations, or the connection of quadratic functions with other concepts, such as function transformations.

On the visual indicator, students can determine several points and plot them on the Cartesian plane, but they have not yet been able to relate them to the characteristics of quadratic functions, such as symmetry, the shape of the parabola, and the position of the vertex. On the symbolic indicator, students are relatively more capable when problems are presented directly in symbolic or graphical form, but they experience difficulties when information is presented in the form of a story and must first be modeled. On the verbal indicator, students are generally able to provide an initial answer or carry out part of the procedure, but they have not yet been able to construct mathematical reasoning, function characteristics, and conclusions coherently and completely.

Students' difficulties do not lie solely in the use of one particular form of representation, but also in the fact that conceptual connections among representations have not yet been established. The solution steps chosen by students still tend to be based on procedural habits derived from familiar problems and are not yet fully grounded in an intact conceptual schema. Therefore, the teaching of quadratic functions needs to be designed not only to train symbolic procedures but also to emphasize the meaning of functions, the integration of visual-symbolic-verbal representations, and the connection of quadratic functions with other concepts so that students' mathematical argumentation can develop more effectively.

Recommendations

Based on the findings of this study, mathematics instruction on quadratic functions should not focus only on procedural symbolic work, but also on helping students connect visual, symbolic, and verbal representations in a more integrated way. Students need to be guided not only to calculate, but also to interpret function notation, read and construct graphs meaningfully, and explain mathematical reasoning in written form. In particular, teachers should provide more learning activities that help students distinguish f(x) from f(x – a), relate algebraic changes to graphical transformations, and connect the vertex concept across symbolic, visual, and verbal forms.
In addition, classroom tasks should be designed not only in familiar routine forms, but also in forms that require students to interpret information from graphs, verbal contexts, and multiple representations. Such tasks may help students move beyond habitual procedures and develop stronger conceptual connections among representations. Future research is recommended to explore instructional interventions that specifically support representational integration in quadratic functions, especially in function notation, graph transformation, and mathematical verbalization.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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