Peirce's Semiotic in Computational Thinking for Mathematical Problem-Solving Process

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Computational thinking is significant in the 21st century, especially for problem-solving. For students, this process requires problem understanding that can apply semiotic perspective. According to Peirce, semiotic components include representament, object, and interpretant, the components that exist in computational thinking as it encourage students to think logically and appropriately. This research is a qualitative case study with one student as its object to receive tasks on problem-solving and interviews. The study results indicate that in semiotics, the object component of the study refers to the ability to understand the given problem, mathematical model, and information that is known from the task given. The representament refers to the student's ability to interpret any given object in computational thinking, such as writing down a function formula and drawing a graph. As for interpretant, students must prove the ability to interpret and give meaning to the problem. Therefore, a semiotic perspective in computational thinking can help identify students' problem-solving.

Keywords: Peirce's Semiotic, computational thinking, mathematical problem-solving process

INTRODUCTION

One of the mathematics learning objectives is to make students understand the problem and solve it appropriately (Sutawidjaja & Afgani, 2015). The goal of mathematics learning is to solve mathematical problems where in the process, it enables students to understand, design a mathematical model, solve the problem, and interpret the solution to encourage logical and critical thinking and meticulousness (Mawaddah & Anisah, 2015) (Widjajanti & Jurusan, 2009). Problem-solving skill is significant at school as students must be able to solve problems at all levels of formal education.

Teachers can measure students' understanding by realizing their different levels of problem-solving and responses to it; thus, they can provide active mathematics learning to enhance students' problem-solving skills (Anisa, 2014). The lack of teacher concern for students' problem-solving process will result in students' inadequate mathematics achievement; thus, students consider mathematics challenging and dull (Utari, Wardana, and Damayani, 2019; Pardimin and Widodo, 2016). Monotonous learning and less-variation learning methods often need improvement in mathematics learning to avoid students' boredom and inconvenience. (Bakhri et al., 2019). The problem occurred because students needed a precise problem-solving method and enough critical thinking and problem-solving skills (Mulhamah & Putrawangsa, 2016).

Proper understanding and representation of a given problem will help students arrange and solve it; thus, they need a reference or symbols for that purpose as semiotic sources. Chandler (2007) defined semiotics as science on signs referring to symbols. Ernest (2006) also stated that the semiotics perspective in mathematical activities, such as problem-solving, provided an alternative to comprehending mathematical teaching and learning concepts.

Charles Sander Peirce, one of the semiotics figures, defined *semiotics* as a study of signs (Presmeg et al., 2016). Peirce's semiotics symbol includes three interrelated components: representament or sign-vehicle, object, and interpretant. According to Peirce, symbols can identify problem-solving processes to determine students' understanding and representation of generated solutions. Computational thinking is one method to encourage students to solve mathematical problems using critical thinking skills (Lockwood & Mooney, 2017).

This skill is the thought process involved in formulating a solution to a problem coherently and systematically, as often occurs in computational steps. However, it is significant for students to apply it in mathematics and other fields (Lee et al., 2014). Computational thinking is significant for students as it covers more than problem-solving methods (Masfingatin & Maharani, 2019). Computational thinking and mathematics are interrelated as the former enriches science and mathematics learning, while the latter is the science application to support computer technology development (Maharani et al., 2019). Mathematics requires direct-experience learning to improve problem-solving skills (Sung et al., 2017). Therefore, students can improve their mathematical concepts by applying computational thinking to solve problems (Masfingatin & Maharani, 2019).

Computational thinking and problem-solving are interrelated, as students' thinking activity becomes the basis for problem-solving (Wantika, 2019). Mathematical problem-solving includes the mathematical concepts, skills, and processes an individual uses to solve a mathematical problem (Utari et al., 2019). The National Council of Teachers of Mathematics (NCTM) proved that problem-solving was essential for students as one of the primary purposes of mathematical learning. Computational thinking includes several aspects: decomposition, pattern recognition, abstraction, and algorithm (Dong et al., 2019) (Selby, 2018). Therefore, computational thinking must convey the earlier aspects to encourage students to solve problems.

A study (Susanti & Taufik, 2021) on university students' computational thinking from the governance science study program in solving statistics problems showed that they already applied all indicators of computational thinking, including decomposition, pattern recognition, abstraction, and algorithm design. The highest percentage in that study refers to the algorithm (84%), and the lowest is decomposition (65.5%). Conversely, the most common failure is due to the need for students' experience in problem-solving structurally. Additionally, a study (Nuraisa et al., 2019) also proposed that students were only in the decomposition or pattern recognition stages while solving the problem. They could not evaluate their result appropriately and showed incoherency during algorithmic design because students could not finish the tasks within the appointed time during the abstraction. These studies should have detailed the students' methods of recognizing and solving the problem based on the computational thinking aspects, including decomposition, pattern recognition, abstraction, and algorithm. It requires further study to identify how students solve mathematical problems using computational thinking based on Peirce's semiotic. Thus, this study aims at identifying students' semiotics perspective on the computational thinking used to solve mathematical problems.

METHODS

This qualitative study used a case-study approach (Creswell, 2014). The specific approach of this study is descriptive (Cohen et al., 2018). This study aimed at the mathematics science study program of

Universitas Muhammadiyah Malang with 33 students involved based on their high scores on Problem-solving Assignments and their ability to communicate their assignment results. They also took the Operational Research course with algebra as its mandatory pre-course subject. There was only one study program to have an in-depth identification and exploration of how students solve mathematical problems.

Data collection was through a problem-solving assignment consisting of only one problem on optimizing a linear program. This problem considered the criteria to identify computational thinking processes in the form of non-routine (complex) problems and those that can undergo decomposition. The researcher observed and directed intrapersonal interviews with the students by giving directions and symbols whenever finding a blockage. Next, after completing problem-solving, students engaged in another interview session, referring to their result in the required task by questioning aspects of computational thinking and Peirce's semiotics components.

Computational Thinking Analysis

This study focuses on computational thinking problems that students might encounter. The researcher reviewed the computational thinking process as a cognitive activity that involves logical analysis in solving problems which include several aspects: problem identification, problem decomposition, pattern recognition, abstraction, algorithm, and debugging (Labusch et al., 2019) (Selby, 2018) (Dong et al., 2019) (Huang et al., 2021). Table 1 describes the computational thinking used during the identification and analysis processes.

TABLE 1
COMPUTATIONAL THINKING ASPECTS

No	Aspec	Description
1	Problem Identification	Identifying problems to solve
2	Problem Decomposition	Outlining problems into several sub-problems
3	Pattern Recognition	Recognizing the pattern from the given problems
4	Abstraction	Identifying significant parts of the problem
5	Algorithm	Producing step-by-step solutions with appropriate sequence
6	Debugging	Deleting inappropriate failure/ procedure and improving it

Peirce's Semiotics Analysis

This study will identify the computational thinking aspects based on Peirce's semiotics that including representament/ sign vehicle, object, and interpretant (Sáenz-Ludlow & Kadunz, 2016). representament/ sign vehicle results from representation in the form of physical or mental references. At the same time, the interpretant is the effect of representament, an interpretation process of the representament. *Semiotics* is the process that occurs within the relationship among representament, object and interpretant. *Semiotics* is a continuous process that improves through interpreting a representament and conceptualizing an interpretant to become a representament in the next stage. This activity becomes a recurrence event. The process is completed when students find a final result or conclusion. The following Table 2 represents the Peirce semiotic components used in this study. The process is completed when students find a final result or conclusion. The following Table 2 represents the Peirce semiotic components used in this study. Table 2 is an analysis result of students' responses during the interview.

TABLE 2
SEMIOTICS COMPONENTS

No	Components	Coding	Description
1	Object	O	Physical or mentally object
2	representament	R	Object's representation
3	Interpretant	I	The efect result from the representament

RESULT AND DISCUSSION

Identifying semiotics perspective in computational thinking to solve mathematical problems refers to students' answers. Figure 1 represents students' responses to questions made by the researcher. The problem is to find out the profit a herb vendor can benefit. The answer to this problem is to require students to apply computational thinking aspects in completing their tasks.

From the problem-solving analysis using computational thinking, the next step was analyzing the reference object for the solving process and how students represented it to get the representament. Afterwards, students would interpret the representament to obtain interpretant.

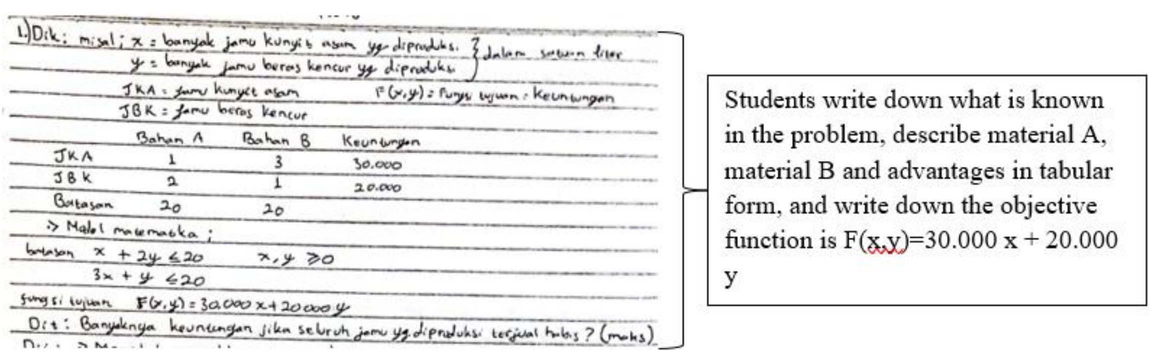
Sáenz-ludlow (2007) emphasized that semiotics is a continuous process; therefore, computational thinking also acts as one. Interpretants from problem identification can become representament for problem decomposition, while interpretants from problem decomposition can become representament for pattern recognition, a process which will continue to the algorithm stage.

Problem Identification

Students recognize problem identification by listing all aspects acknowledged from the problem. Students can also explain in detail the purpose of solving the problem.

Figure 1 is the student work result and interview transcription during problem identification process.

FIGURE 1
STUDENT WORK RESULTS FOR PROBLEM IDENTIFICATION



Researcher: What is the exact problem you are going to solve?

Student: I am looking for the maximum profit from herb sales produced by Bu Lutfi, a wealthy herb drink businesswoman. For example, X represents the turmeric-tamarin herbal drink, and y represents the rice-galanga drink. Eventually, I could find out the profit for both products: Rp 30,000 and Rp 20,000.

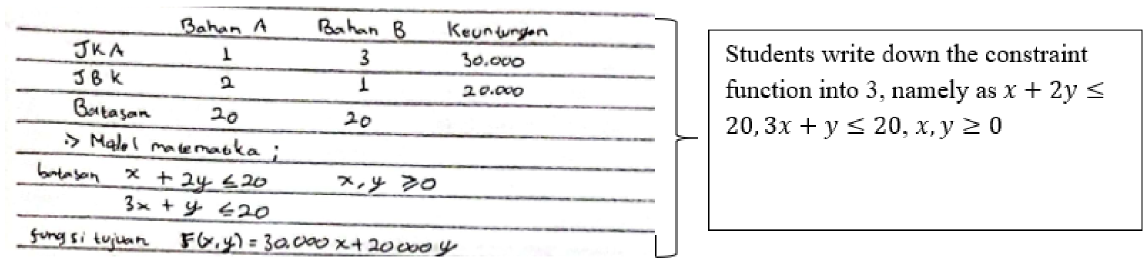
Based on the student responses and interview transcription, the object to recognize the problem is the profit value, an aspect that appears within the question of the problem. Next, students would represent it into *F (x, y)* = Purpose aim = profit.

The interview result showed that students would interpret or provide meaning for their representation by looking for the maximum profit from both products' sales. Students explained the problem by relating it to the sales profit of the two products.

Problem Decomposition

In this stage, students presented the tables they made for the presentation. The table consists of the ingredients list for herbal drinks and the profit from each sale. Next, students interpreted the lists in a mathematical function for each drink as $x + 2y \leq 20$, $3x + y \leq 20$, $x, y \geq 0$ and $z = 30.000\,x + 20.000\,y$, as in the following excerpt of the student result in Figure 2 and interview transcription.

FIGURE 2
STUDENT WORK RESULTS FOR PROBLEM DECOMPOSITION



Researcher: Why did you choose to use that table?

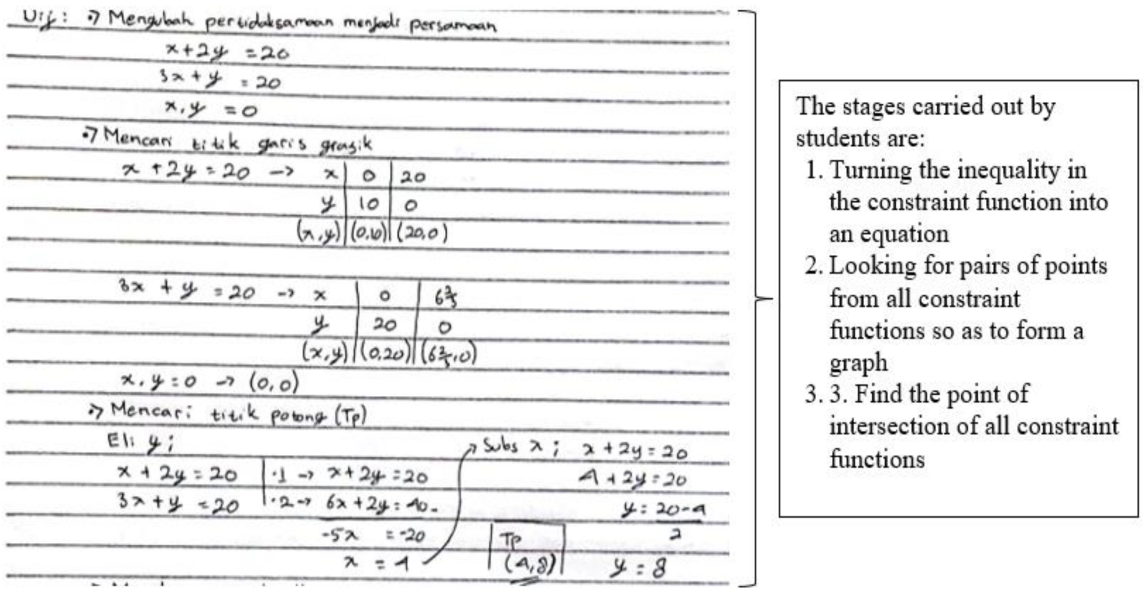
Student: I used this table to explain the ingredients and profit for each herbal drink, Ma'am. Based on the problem, the turmeric-tamarin drink requires one portion of ingredient A and three portions of B, resulting in Rp 30,000 profit. At the same time, the rice-galanga drink requires two portions of ingredient A and 1 of B, resulting in Rp 20,000 profit. Additionally, the top portion of each ingredient is 20.

Students explained that the table makes them easier to determine the function used to determine the profit.

Pattern Recognition

Students make several steps to determine x and y values from the function of the specified obstacle. Students construct the function as a mathematical model: $x + 2y \leq 20$, $3x + y \leq 20$, $x, y \geq 0$ dan $z = 30.000\,x + 20.000\,y$. Next, the subject interprets the mathematical model by looking for x and y values. The values come from transforming the model into an equation and eliminating x or y to zero. Consequently, we can find out the ordered pair in the cartesian coordinate. Figure 3 is a student work result.

FIGURE 3
STUDENT WORK RESULTS FOR PATTERN RECOGNITION



The following is an excerpt of the interview transcription.

Researcher: After you found the obstacle and purpose functions, what came next?

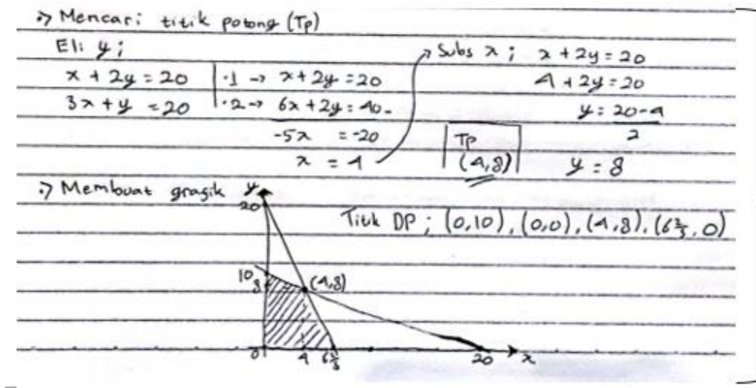
Student: I found two variables from each function, the x and y. I transformed them into an equation to find their values by eliminating one variable consecutively. Thus, I found the ordered pair. After that, I looked for the intersected point of the two linear functions, enabling me to find its maximum value.

Figure 3 and interview also found that students could describe the process of looking for the x and y values; thus, they could determine the maximum value from the intersected point of both linear functions.

Abstraction

Students produced graphs, determined the sets of solution areas, and located the intersected point of the two linear functions. The following result of student work in Figure 4 and interview transcription shows the use of semiotics when students produced graphs during the abstraction process.

FIGURE 4
STUDENT WORK RESULTS FOR ABSTRACTION



The next stage is carried out with the subject making a graph and placing all the points on the constraint function on the graph, so that a pair of points that fulfill the set of solutions is obtained

Researcher: Why did you draw a cartesian coordinate?

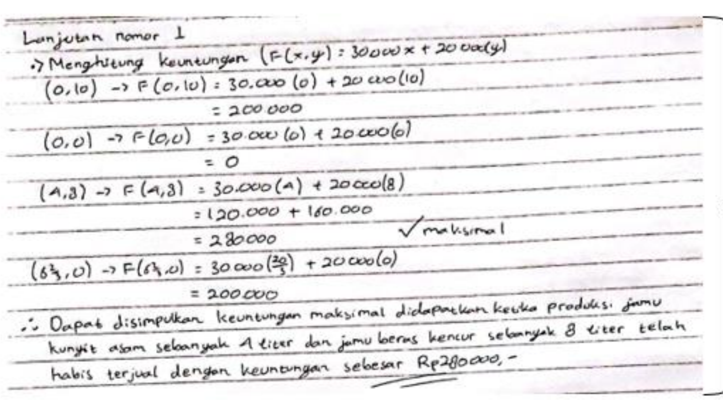
Student: I made it to help me determine the sets of solution areas by referring to point x and y representing it.

Figure 4 and the interview excerpt described that the subject referred to each obstacle function's x and y values. From the representation, the subject concluded that the values would make an easier effort to determine the ordered pair in the cartesian coordinate in finding the solution set areas.

Algorithm

The following stage is an algorithm where students determine the maximum value of the purpose function by substituting the x and y values from the intersected of both lines. The result and analysis of the interview found that the object in this process is the intersected point from each line. Afterwards, students presented the result into coordinate pairs as follows: $A(0,0), B = \left(\frac{20}{3}, 0\right), C(4,8)$ and $D(0,10)$. Referring to those pairs, students explained the substitution process in the purpose function to find the values of points A, B, C, and D, where one of them was the maximum value of herbal drinks sales. The following is an excerpt of the interview transcription and Figure 5 is student work result.

FIGURE 5
STUDENT WORK RESULTS FOR ALGORITHM



Students calculate profits by substituting all the points which are the settlement set into the objective function so that all sales profit values are obtained.

Researcher: What is the next process to find the maximum value?

Student: After finding the intersected point, I described it by writing it down in points A, B, C, and D to find the maximum value. Thus, the maximum profit is Rp 280,000 from four turmeric-tamarin and eight rice-galanga drinks.

The algorithm process analysis found that students could determine the profit value from one appointed point. Students found that the maximum value was Rp 280,000 by selling *four turmeric-tamarin and eight rice-galanga drinks.*

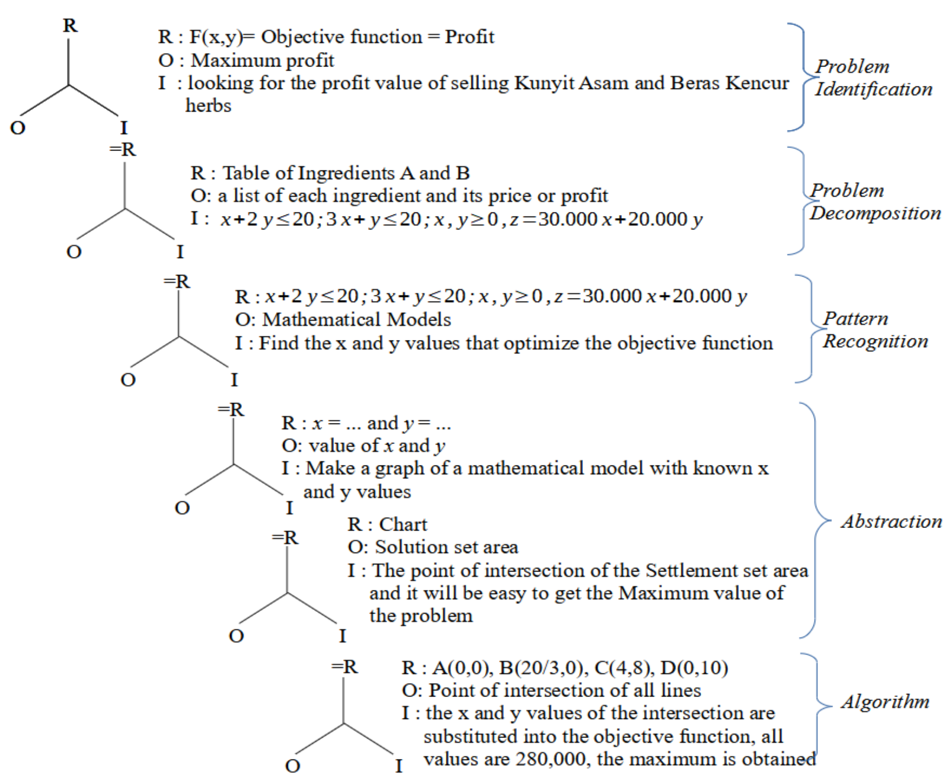
Debugging

Students did not conduct debugging, and the subject stated that the processes already met the purpose; thus, they found the maximum profit.

Based on the answer and excerpts of the interview transcription, students have performed the computational thinking process according to the appropriate stages despite some undetailed explanations from students. The semiotics components comprising representament, object, and interpretant were identified.

Students represented it by writing the function, table, inequation and equation functions, variables, graphs, and coordinate points. While the object received several questions on problems, acknowledged lists and values, mathematical models, and solution set areas. As a result of representament interpretation, interpretants expressed students' opinions about the representation. Students described the interpretant by expressing the stages they underwent, such as looking for the x and y values, making graphs, determining the intersected point, and looking for the profit by substituting the intersected points in the purpose function. Figure 6 shows the identification result of Peirce semiotics in computational thinking process.

FIGURE 6
PEIRCE'S SEMIOTICS IN COMPUTATIONAL THINKING PROCESSES



DISCUSSION

Computational thinking has become a common topic in several published articles, such as its integration with STEM (Srisangngam, 2020), the implication in programming (Rodríguez-Martínez, 2020), implementation in K-12 curriculum (Chen & Huang, 2017) and problem-solving (Yadav et al., 2016). This finding proposed that computational thinking is significant for students. Hu (2011) defined computational thinking as a method for solving problems, system automatization, and changing data by building smodels and representation, concrete and abstract, to represent the model at best. Aspects of computational thinking, problem identification, problem decomposition, pattern recognition, abstraction, algorithm and debugging do not necessarily occur sequentially (Hu, 2011). Therefore, Peirce semiotics is appropriate to identify computational thinking as it has a representament component, the representation result of a reference object in the problem-solving process, and students' interpretation of the model and how they use it as the material for the following process.

Problem-solving in computational thinking indicates that technique applications, such as computers, can help students solve real-life problems involving mathematical modelling (Voskoglou & Buckley, 2012). Otte (2006) explained that mathematical epistemology from a semiotics point of view refers to genetic epistemology stating all mathematical activities that are real and related to mathematical entity representation in a continuous transformation. The Semiotics perspective provides an alternative to understanding teaching concepts and mathematical learning (Ernest, 2006). Symbols and representations from semiotics are a significant part of learning and problem-solving. For example, a study by Ernest (2006) on the semiotics perspective in number cases stated that learning the number semiotics system and counting suggested that students could participate in a particular social practice where they could express and produce the appropriate number symbols. In line with this result of the study, students can understand the optimization concept by representing each object marking the problem-solving process in every computational thinking aspect and interpreting the results. Nevertheless, since representament refers to an object, semiotics encourages students to clarify the mathematical object characteristics. Additionally, words and symbols in the representation process are inadequate to support learning and problem-solving processes; yet, the strong correlation among representament, object, and interpretant must be included in the learning process to achieve an in-depth understanding (Mudaly, 2014).

CONCLUSION

Based on the result of the study, students have applied the semiotics perspective in computational thinking to identify their understanding of problem-solving activities. The components of Peirce's semiotics include representament, object, and interpretant. representament appears in table, function, equation and inequation functions, drawing variables, graphs, and points. The objects received a list of questions on the given problem; the detail acknowledged components of the problem, acknowledged values, mathematical model, solution set areas, and intersected points. Further, interpretants, as a result of representament express expressed students' opinions related to the representation used in their process. As this study has yet to identify the problems used for this practice to the maximum extent, especially decomposition problems, it is strongly suggested that the upcoming study use problems that can identify all aspects of computational thinking.

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