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Students' learning obstacles in systems of linear equations in two variables related to mathematical computational thinking skills

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Abstract

Integrating computational thinking into Programme for International Student Assessment (PISA) assessments presents a significant challenge for Indonesian students, particularly in mathematics education. Despite its crucial role in problem-solving, computational thinking has not been widely implemented by students due to the presence of learning obstacles. This study aims to identify the learning obstacles that junior high school students encounter in understanding systems of linear equations in two variables, specifically about their computational thinking abilities. A qualitative approach with a phenomenological method was employed. Research instruments included a computational thinking test and a semi-structured interview guide. Data were collected from 20 students at a junior high school in Wonosobo Regency, Indonesia. Data analysis consisted of three stages: reduction, display, and conclusion. The findings reveal that students experience three types of learning obstacles—epistemological, ontogenical, and didactical when engaging with systems of linear equations in two variables, indicating that these obstacles hinder the development of their mathematical computational thinking skills.

Keywords: computational thinking; learning obstacle; systems of linear equations in two variables

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I. Introduction

As a universal language that understands the basic structures, patterns, and relationships between various concepts and objects, mathematics is central to developing science and technology. It has opened the door to a deeper understanding of the world around us and helped solve various everyday problems from ancient times until the modern era. Our findings are consistent with Cockcroft's (1982) statement that living an everyday life in the 20th century without mathematics is nearly impossible. This is why mastering mathematics is essential for facing the rapid development of science and technology.

The rapid development of science and technology brings up a specific challenge Indonesians face, especially for the young. Technological development and globalization have changed job mapping and competency requirements. They also encourage education to develop 21st-century skills such as communication, collaboration, critical thinking, - problem-solving creativity, and innovation (Widodo & Wardani, 2020). These science and technology developments have indeed raised global competition. As the nation's next generation, students are demanded to master superior skills compared to others worldwide. However, ironically, Indonesians' skills in mathematics and science are very weak (Ansori, 2020). Indonesian students have not achieved satisfactory results in international education system evaluations, such as the Program for International Student Assessment (PISA). The latest PISA results, 2018, showed that their average scores in mathematics were only 379 out of 487 (OECD, 2019). This indicates that the average mathematics level only reaches level 1, whose low score limit is 358. In PISA, the highest score is in level 6, with a low limit score of 669. Therefore, the mathematical skills of Indonesian students are still below the average of students from other PISA countries. Meanwhile, mathematics crucially plays a significant role in various fields of science and in the development of mathematics itself (Siagian, 2016).

Based on PISA results, Indonesian students' low mathematics skills also indicate low skills in solving mathematics problems. This is in line with the previous studies conducted by Mawardi, Arjudin, Turmuzi & Azmi (2022), Rizki, Prayitno, Hikmah & Turmuzi (2021), Utami & Wutsqa (2017), and Ratna & Yahya (2022). All these previous studies show students' relatively low skills. This low skill can be caused by their lack of understanding of mathematics concepts and materials. Therefore, when the students process the mathematics problems, they encounter obstacles. These obstacles cause them to be mistaken when answering the problems (Rizki, Prayitno, Hikmah & Turmuzi, 2021).

Improving problem-solving skills requires skills to analyze problems, identify thinking patterns, draw conclusions, etc. Computational thinking is one of the most widely applied problem-solving techniques (Anggriani, 2023). Megawati et al. (2023) are in line with this. They state that computational thinking is a process of solving problems by adopting computer science by employing logic to determine effective, efficient, and optimal solutions. As a way of understanding and solving complex problems that use computer science techniques and concepts such as decomposition, pattern recognition, abstraction, and algorithms, computational thinking is seen by many experts as one of the skills that support many dimensions of 21st-century education (Ansori, 2020). Computational thinking also sharpens logical, mathematical, and mechanical knowledge and modern knowledge about technology, digitalization, and computerization. It can establish a confident, open-minded, tolerant, and environmentally sensitive character (Kalelioğlu, 2018). According to Doleck, Bazelais, Lemay, Saxena & Basnet (2017), computational thinking is a fundamental skill required for students. In line with this, Mohaghegh & Mccauley (2016) state that computational thinking skills are among the 10 skills people must master nowadays.

The Organization for Economic Cooperation and Development (OECD) released the PISA 2022 framework, in which computational thinking skill is included in the PISA assessment (OECD, 2023). In daily life and the context of mathematics problem solving, computers and computing tools have increasing and expanding roles. This is reflected in the PISA 2022 framework, which declares that students should possess and be able to demonstrate computational thinking skills when they apply them in mathematics as part of problem-solving practice (OECD, 2023). In addition, along with increasing technology's dominant roles in their lives, long-term mathematical literacy must include a synergistic and reciprocal relationship between mathematical thinking and computational thinking (OECD, 2023). This is undoubtedly an opportunity for Indonesian students to hone and develop computational thinking skills to compete in the development of science and technology.

Computational thinking skill, introduced by Jeanette Wing, is a thinking process that involves solving problems by applying computer science concepts (Wing, 2006). This definition refers to the computer science role in developing computational thinking skills. However, Barr & Stephenson (2011) show that computational thinking can be applied in various scientific disciplines. This aligns with Jeannette Wing's view, which claims that computational thinking is a fundamental skill for everyone, not just computer scientists. She argues that integrating computational ideas into other school subjects is essential (Maharani, Nusantara, As'ari & Qohar, 2020). Thus, computational thinking skills can be applied to mathematics to establish students' problem-solving skills.

Since mathematics should be comprehended integrally, applying computational thinking is crucial (Weintrop et al., 2016). In mathematics, computational thinking skills are classified as Higher Order Thinking (HOT), which helps students solve problems (Henderson, Cortina, Hazzan & Wing, 2007). According to Maharani et al. (2020)., computational thinking includes 4 main elements, namely 1) Decomposition, Analyzing problems to parse them into smaller parts; 2) Pattern recognition, Observing patterns, trends, and regularities in data; 3) Abstraction, Identifying the underlying principles that produce the perceived pattern; 4) Algorithm design: Developing the steps or instructions for solving problems. Still, computational thinking provides learning experiences that establish and develop the following attitudes: Apart from that, computational thinking also provides learning experiences that foster the following attitudes: 1) Self-confidence in dealing with situations; 2) Persistence in working under complex problems; 3) Ability to handle ambiguity; 4) Ability to handle open-ended problems; 5) setting aside differences when working with others in order to achieve shared goals or to find out solutions; and 6) knowing someone's strengths and weaknesses when working with others (Barr & Stephenson, 2011).

Unfortunately, despite its advantages, schools still do not implement computational thinking optimally. This is emphasized by Azmi & Ummah (2021) who state that computational thinking skills in Indonesia still cannot be implemented optimally. Previous studies also indicate that students' computational thinking is still relatively low. A previous study was conducted by Amelia (2020) on mathematics teachers at MTs Islamiyyah Ciputat. The teachers stated that students still needed to develop their computational thinking skills. The teacher also considered that computational thinking skills were something general. Every student has to possess it. However, it was still hard to implement, so the problems assigned to the students were only typical. Still, Mufidah (2018) presents the results of her research and observations on MTs Bustanul Ulum Sembujo students in December 2017 in Table 1.

Table 1. Test score computational thinking skills

No.	Computational Thinking Skills	Score	Interpretation
1	Decomposition	50	Low
2	Pattern recognition	47	Low
3	Abstraction	41	Low
4	Algorithm	62	Moderate

Low mathematical computational thinking skills certainly lead to students' low ability to solve problems since computational thinking skills help students to overcome problems (Henderson et al., 2007).

Implementing computational thinking skills can be conducted through learning experiences supplemented by carefully planned learning by the teachers. However, its implementation does not always go well. Students often face challenges and obstacles that hinder them from achieving their learning goals. According to Brousseau (2002), there are three types of obstacles that students may face, namely 1) epistemological obstacles, which are caused by the limited knowledge that students have in a particular context; 2) ontogenic obstacles, which are caused by students' limitations in their self-development or their mental preparation; 3) didactical obstacles, which emerge from the methods or approaches used by the teacher.

Although previous studies have explored learning obstacles students face in studying statistics about computational thinking skills, there remains a paucity of research focusing specifically on learning obstacles within the topic of systems of linear equations in two variables associated with computational thinking abilities. This gap highlights the need for further investigation, motivating the present study to identify the learning obstacles junior high school students encounter when learning systems of linear equations in two variables in the context of computational thinking development.

II. Research Methods

This research employs a qualitative approach by applying a phenomenological design as the first stage in Didactical Design Research (DDR). Didactical Design Research (DDR) is a research approach that identifies and minimizes learning obstacles based on students' responses, thereby producing effective instructional designs and teaching materials. Phenomenological design is one type of qualitative research that adopts an interpretive paradigm. This research aims to describe students' learning obstacles in learning systems of two-variable linear equation materials related to their computational thinking skills by referring to their understanding and experience.

The subjects of this research were 20 8^{th}-grade students at SMP Negeri 2 Kaliwiro, Regency of Wonosobo. These students already knew about the materials on two-variable linear equation systems. They were selected using a purposive sampling technique. The data in this research were collected using interview and test techniques. Data analysis followed Miles and Huberman's stages of data collection, reduction, presentation, and conclusion verification (Rijali, 2018).

The test was conducted to figure out students' computational thinking skills. Meanwhile, students who experienced learning obstacles when working on the provided questions were interviewed using semi-structured interviews. The test instruments on computational thinking skills had been adjusted based on the expert's responses, who is a lecturer. This test contains one question that has been adjusted based on indicators of computational thinking skills. After that, the teacher and some students who had experienced learning obstacles were interviewed at school. The data gained were analyzed by reducing data, presenting data, and drawing conclusions to gain information on learning obstacles undergone by the students.

III. Results and Discussion

Result

The results of the research are the test answers on computational thinking skills, which indicate that there are learning obstacles experienced by students. The question and answer of the test on computational thinking skills and interviews with the teachers and students can be seen as follows:

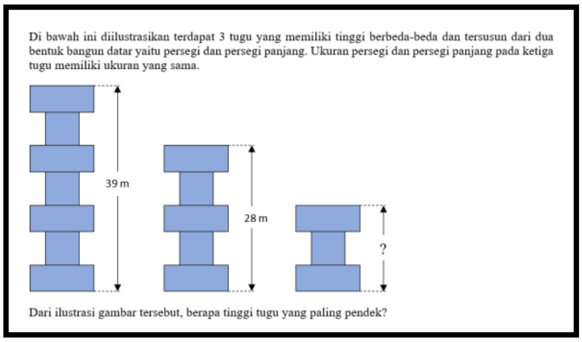

Figure 1. Computational thinking test questions

In the question above, students are asked to find the height of the shortest monument. Students' answers were expected to reflect computational thinking skills, whose indicators are decomposition, pattern recognition, abstraction, and algorithm.

Based on the test results given to 20 students of 8th-grade students of Junior High School, four answers were taken, and the following results were obtained:

1. Student 1

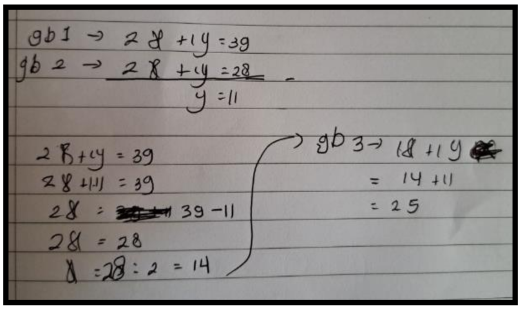

Figure 2. Answer of student 1

Based on Figure 2, Student 1 did not state the given information or the questions asked. Student 1 did not simplify the problem first or did not parse the information into simpler ones. This shows that student 1 did not use decomposition indicators to easily solve problems by writing down the information from the questions. Still, student 1 wrongly found the pattern to answer the provided question. The mistake in recognizing the pattern affected the following steps to solve the problems. Therefore, student 1 already recognized the pattern but failed to reach abstraction and algorithm indicators in computational thinking. Student 1 did not reach abstraction due to the mistake, and no conclusion was drawn. Student 1 was also interviewed. Here is the interview:

Researcher: Have you learned the materials on systems of linear equations in Two variables?

Student 1: Yes, I have, Sir.

Researcher: Do you understand the material on systems of linear equations in two variables?

Student 1: Not really, Sir

Researcher: How did you find out that there are two equations formed by $2x + 1y = 39$ and $2x + 1y = 28$?

Student 1: I thought of rectangles and squares as x. Thus, when they were combined, they made $2x$. For y, I consider it as an individual monument.

2. Student 2

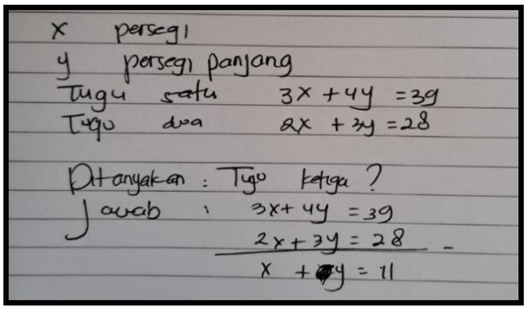

Figure 3. Answer of student 2

Based on Figure 3, Student 2 noted both the known information and the questions from the problem, but the details were incomplete. Student 2 achieved the decomposition indicator by writing down the information provided so it looked simpler. Still, student 2 also figured out the patterns by arranging Equations 1 and 2. However, student 2 could not continue answering after that. This means abstraction and algorithm indicators in computational thinking have not been achieved yet. Student 2 was also interviewed to determine why the answers were not completed. Here is the interview:

Researcher: Have you studied the materials On systems of linear equations in two variables?

Student 2: I think I have.

Researcher: Do you understand the material on systems of linear equations in two variables?

Student 2: Not yet, Sir

Researcher: How did you figure out that there are two equations formed by $3x + 4y = 39$ and $2x + 3y = 28$ from the problem?

Student 2: From the picture of the tallest monument and the medium one, Sir (while pointing at the question picture)

Researcher: OK. Can you explain?

Student 2: It was known that the first monument had three rectangles; the other four were squares. The

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	height of the monument was 39 meters. If the rectangle was x and the square was y, the equation is $3x + 4y = 39$. This applied to the second monument as well.
Researcher:	Then why didn't you completely answer it?
Student 2:	I forgot how. When this material was explained, I did not understand it.

3. Student 3

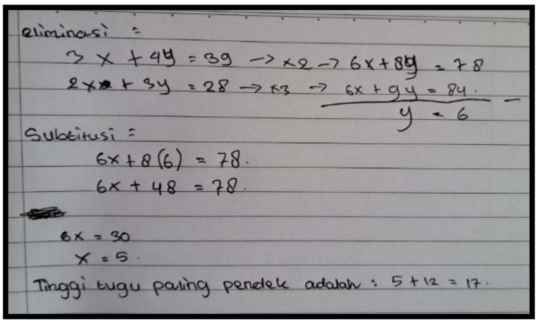

Figure 4. Answer of student 3

Based on Figure 4, it can be found that student 3 did not write down what was known nor asked about the problem given. Student 3 did not parse the problem into simpler information. However, the interview on student 3 outlines what information was known and asked about the problem. This interview proves that:

Researcher:	Have you studied the material on systems of linear equations in two variables?
Student 3:	Yes, I have, Sir
Researcher:	Do you understand the material on systems of linear equations in two variables?
Student 3:	I understand enough, Sir
Researcher:	How did you figure out that there are two equations formed by $3x + 4y = 39$ and $2x + 3y = 28$ from this problem?
Student 3:	From the picture, the first monument and the second monument (while pointing at the picture)
Researcher:	Can you explain it?
Student 3:	The first monument had three squares and four rectangles. Its height is 39 meters. Then, if x was the square and y was the rectangular y, the equation was $3x + 4y = 39$.
Researcher:	What about this equation $2x + 3y = 28$?
Student 3:	From the second monument. There were two squares, three were rectangular, and their height was 28 meters, so the equation was $2x + 3y = 28$
Researcher:	Then, you did elimination and substitution, right?
Student 3:	Yes, I did, Sir. I did it to determine the height of the third monument (the shortest one).
Researcher:	Why didn't you write down the information from the questions?
Student 3:	I scribbled on the other paper, Sir.

From student 3's answer and interview, it was found that student 3 started the thinking process by parsing the problems into important details. However, these details were not written on the answer sheet. Student 3 simplified the problem. In computational thinking, we call this decomposition. Next, student 3 could recognize the pattern (pattern recognition). It was proven when student 3 directly related the problem to the material or concepts of two-variable linear equations by creating the first monument's equations, which were $3x + 4y = 39$ and $2x + 3y = 28$ for the second monument.

Unfortunately, student 3 did not conclude the following stage. Student 3 immediately looked for the shortest tower height by just making a substitution, namely 5 + 12 = 17. Thus, student 3 had not yet reached the abstraction indicator in solving the problem given. Still, student 3 has not yet reached the algorithmic thinking stage either because the stages to solve the problems were incomplete and unsystematic.

4. Student 4

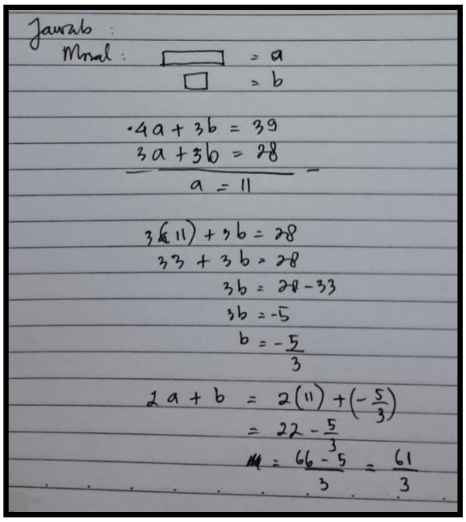

Figure 5. Answer of student 4

Based on Figure 5, it can be found that student 4 did not write down either what he knew or what he was asked about. Student 3 simplified the problem given, but it was not finished. Next, student 4 immediately exemplified that the rectangular monument was a, and the square monument was b. The equation for the highest monument is 4a + 3b = 39. However, student 4 made a mistake when making the second equation because he was careless. He made the equation as 3a + 3b = 28 instead. This mistake affected the following steps, which were elimination and substitution. Therefore, student 4 has reached pattern recognition despite a mistake when making the equation.

Meanwhile, student 4 did not draw conclusions regarding the solutions found at the abstraction stage. Thus, of course, student 4 certainly has not reached the algorithmic thinking stage because there were errors and incomplete and systematic stages in solving the given problem.

An interview was conducted with the mathematics teacher to explore the instructional strategies used in teaching systems of linear equations in two variables. The interview also aimed to identify potential student errors stemming from the teaching process. This section summarizes the key points from the interview excerpts regarding the instructional sequence for the topic.

Researcher: How do you introduce systems of linear equations in two variables material to your students?

Teacher: Usually, I ask students to read their textbook first. Then, I explain the topic of systems of linear equations in two variables by introducing the concept and relating it to real-life problems. Afterward, I provide examples from given problems and demonstrate how to solve them using the elimination and substitution methods.

Researcher: How do you explain it?

Teacher: I write down a problem on the whiteboard. I took the problem from the book. Then, I will show you how to answer it. I also ask the students to look at the examples in the book to solve the existing problems.

Researcher: Did each student say that they understood the systems of linear equations in two variables?

Teacher: I can't guarantee that all students understand the material because I do not confirm one by one. Most students solve the questions based on my explanation and from the textbook as well. The textbook also provides examples of problem-solving. That is why almost all students answer the questions the same way as provided by the textbook.

Researcher: How about the conclusions they gave at the end of the lesson, Sir?

Teacher: Oh, that. They only made small notes regarding the steps I gave. They are easy to remember, especially when doing multiplication equations before elimination and substitution.

Researcher: Do you know about computational thinking skills?

Teacher: I have heard of it but have not looked into it.

The results of the interviews with teachers indicate that students were not allowed to develop their understanding. They were also not taught to understand the information and to parse the problems first. This finding is supported by textbooks presenting examples of problems with direct solutions without providing structured stages of computational thinking skills. This finding emphasizes the view of Sumarni, Darhim & Fatimah (2021). They state that students are less accustomed to recording information that can be identified and described when solving questions. Moreover, teachers do not understand computational thinking skills.

Discussion

From the evaluation of test results and interviews conducted with students, it can be identified that three types of obstacles arise for students when they try to understand the system of equations of two variables, materials related to computational thinking skills. Referring to Figure 2, it can be seen that student 1 had difficulty solving the problem due to a lack of understanding of the concept of solving a system of equations in two variables. Student 1 did not understand the steps to solve it, so students tended to guess without understanding the rules for making linear equations in two variables. The results of these students' work show the epistemological obstacles they faced. Similar findings emerged from student 2's answer, where the student could not solve the problem given. Student 2 stopped answering until the stage of making two linear equations with two variables. Student 2 has not yet understood the concept of elimination and substitution, so student 2 only operates on the two equations without using existing rules.

Meanwhile, the rules were provided and explained in the learning process. The teacher explained how to use the concepts of elimination and substitution to complete systems of linear equations in two variables. This shows that students underwent epistemological obstacles because students have a limited understanding of the systems of linear equations in two variables material concepts. Student's understanding of a mathematical concept is the most important part of the learning process (Sumarni & Nuranita, 2015; Sumarni et al., 2018). In line with this (Maarif, Perbowo, Noto & Harisman, 2019) state that understanding a concept is the foundation for building knowledge.

Besides finding epistemological obstacles, there was also an ontogenetic obstacle. According to Suryadi (Febrina & Prabawanto, 2023), there are three types of ontogenical obstacles that students undergo: instrumental ontogenical obstacles, conceptual ontogenical obstacles, and psychological ontogenical obstacles. Ontogenic psychological obstacles are unpreparedness due to students' psychological aspects, such as low motivation and interest in the studied material. Meanwhile, instrumental ontogenic obstacles are students' unpreparedness regarding technical matters that are key to the learning process, which can be revealed. Furthermore, conceptual ontogenic obstacles are students' unpreparedness related to previous learning experiences.

Meanwhile, didactical obstacles are caused by didactic systems such as sequence factors and presentation stages in classroom learning. Based on the answers given and interviews with Student 1, it can be seen that Student 1 was unable to carry out abstractions and algorithms on the questions given because Student 1 made mistakes and did not draw conclusions about the solutions found. Student 1 did not pay attention to the important information in the problem given, as well. Therefore, it was difficult to recognize the existing problem patterns (pattern recognition). Another ontogenetic obstacle identified is shown by student 2 in Figure 3. Student 2 was unable to determine patterns from the existing information. Student 2 was also unable to solve the questions because he did not understand the concept of elimination and substitution in solving the

SPLDV questions. Students felt they were not ready for the SPLDV material because student 2 felt they did not understand it when they were given the materials. This shows an instrumental ontogenic obstacle due to technical difficulties related to elimination and substitution.

The didactical obstacles indicated in this research can be identified from the teaching process delivered by teachers at school. In line with this, research conducted by Hariyomurti, Prabawanto & Jupri (2020) states that teachers' errors in determining learning methods can result in didactical obstacles. The interviews conducted with informants, namely mathematics teachers, found that the implementation of the learning process did not support students in first building their understanding of the SPLDV material. The teacher tended to explain and give examples of questions about SPLDV immediately. Students should be allowed to construct their understanding so that the concepts they learn are not easily forgotten and can be applied to other problems. Tsao (2006) states that the student learning process will improve when students can construct their understanding. Moreover, the informant also informed that using textbooks in the learning process does not help students develop their skills in the thinking process. Students are instructed directly to find solutions to the problems given. Teachers should be able to implement learning strategies that focus on developing students' thinking skills. This includes computational thinking skills so students can solve problems by paying attention to indicators of computational thinking skills, such as decomposition, pattern recognition, abstraction, and algorithms.

IV. Conclusion

Based on the analysis of students' responses and interviews with teachers and students, it can be concluded that students experience learning obstacles when studying systems of linear equations in two variables related to computational thinking skills. These obstacles include epistemological, ontogenical, and didactical barriers. The epistemological obstacles identified involve decomposition, pattern recognition, abstraction, and algorithmic thinking, primarily due to students' limited understanding of the problem-solving context. ontogenetic obstacles are reflected in students' challenges in comprehending solution steps and performing abstraction or generalization on the given problems. Meanwhile, the didactical obstacles revealed in this study stem from instructional practices that insufficiently emphasize computational thinking skills and provide limited opportunities for students to construct their knowledge optimally.

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