Revealing students' thinking schemes in solving direct current electrical circuit problems

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Abstract
Students' thinking schemes must be revealed to discover the students' fundamental problems in solving direct current (DC) electrical circuit problems. Concept maps and problem-solving can be used to reveal students' thinking schemes. The method used in this study is descriptive qualitative. The research was conducted on second-semester students who took the Fundamental Physics II course at a private university in Madiun in 2023/2024, totaling 9 students. Data was collected using the documentation method in the form of assignments to make concept maps, tests, and interviews. The results of this study reveal students' thinking schemes, which can be categorized into computational thinking (CT), non-CT, and combined thinking (CT and non-CT). Non-CT students' thinking schemes use trial and error methods to solve problems and intuition to conclude.

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1. Introduction

Physics is a part of science that involves definitions (limitations) in describing physical phenomena. In electricity and magnetism, for example, quantities such as current, electric field, and magnetic field cannot be visualized without definition. Electricity and magnetism are abstract, but experimental activities can observe their physical phenomena. Electrical topics are generally experienced by students in their daily lives; the smartphones and laptops they use are inseparable from the basic concepts of electricity. Of course, they also get knowledge of electrical circuits in real life, not only from facilitators or textbooks. Knowledge from various sources can be used to build their thinking process (Faizah et al., 2022), which has the potential to give rise to new concepts. To accommodate or reject new ideas, of course, through systematic thinking stages. The thinking system is a way of seeing and discussing reality that helps us better understand and work with the system (McGlacken-Byrne et al., 2022). The thinking system from the stages of understanding, presenting, and using knowledge is a thinking scheme (Syamsuri, 2016). By knowing the students' thinking schemes, the students' initial conceptions and thinking processes can be identified well.

The topic of electrical circuits is of particular interest to researchers in physics education. Conception and assessment are the most frequently raised topics (Gardon et al., 2021; Ivanjek et al., 2021; Kapartzianis & Kriek, 2014; Kollöffel & de Jong, 2013; Küçüközer & Demirci, 2008; Küçüközer & Kocakülah, 2007; Küçüközer & Kocakülah, 2008; Liu et al., 2022; Nuriyah et al., 2024; Setyani et al., 2017; Suryadi et al, 2020). Series and parallel electrical circuit learning scenarios are also applied to develop student's critical thinking skills (Papadimitriou, 2012). The STEM approach also develops students' cognitive structures (Baptista & Martins, 2023). Contextual learning is also applied (Gottschlich et al., 2024) in electricity learning. Active learning on electricity material is also used, and its influence on attitudes and learning outcomes is analyzed (Akpinar & Korkusuz, 2019). Learning media in electrical circuits has also been carried out (Franchin, 2006; Gustavsson, 2003; Pérez Martínez et al., 2022; Ramnarain & Moosa, 2017; Yadiannur, 2017). From the various studies described, research related to electrical circuits leads to the conception, assessment, and implementation of models, methods, strategies, and media on electricity topics.

Research on electricity (in education) that focuses on fundamental aspects is student conception. Student conception can be revealed by asking questions about the concept and then

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continuing with an analysis of the responses given. It has described that research in physics education related to conception (conception profile and misconception) has been widely conducted. This research reveals the students' thinking scheme. This research is Different from previous studies that focused on the findings of conception, misconception, and its profile. The thinking scheme is made by students using a concept map. Concept maps can provide initial information related to the conceptions held by students. Concept maps allow facilitators and students to present knowledge and visualize the relationships between concepts (Pabón-Galán et al., 2021). Concept maps are arranged by creating the main concept; then, other concepts are written and connected with connecting lines that show the relationships between concepts (Utami et al., 2022). The main idea of a concept map is that conceptual understanding can be assessed by asking students to create a map by connecting concepts in a hierarchical structure using prepositional statements as connectors (Mistades, 2009). The resulting concept map reveals the students' thinking schemes related to the concepts presented.

Based on the description that has been presented, this research provides a response to the problem "How do students think in solving direct current electrical circuit problems?". The thinking scheme in this study focuses on the effective thinking scheme using Computational Thinking. CT is a way of solving problems, designing systems, and understanding human decomposition when facing complex problems by referring to basic concepts or designing complex systems (Dwyer et al., 2014; Wing, 2006). CT is also a form of analytical thinking that solves problems, designs, and evaluates a large and complex system so that it can be implemented in the real world (Herawati et al., 2024). CT uses abstraction and decomposition (Wing, 2006), algorithms and procedures, and automation (Barr & Stephenson, 2011) in solving complex problems. The application of CT can help students in obtaining adequate and efficient solutions. The tendency of students to use CT in solving problems is high, assuming students have complete information related to the problem so that at least they can identify problems and represent solution ideas that are part of the decomposition. Students' tendency to use trial and error in solving problems also has potential, considering their limited knowledge and propensity to use intuition in solving problems.

2. Method

The method used in this study is descriptive qualitative. The results of the concept maps made by students are described and categorized (based on the criteria obtained) by considering (1) the number of concepts written, (2) relationships between concepts, (3) branching, (4) hierarchy, (5) cross-links, (6) examples (Mistades, 2009). The concept maps designed by students are initial information related to their conception. Category guidelines are based on the scores of the concept maps made by students in Table 1.

Table 1. Indicators, criteria, and weighting of students' concept maps

No.	Indicators	Criteria and Scoring			Weight
1.	Number of Concepts Written (NCW)	0 1 2 3 4 NCW<5.	5 6 7 8 9 5>NCW≥10	10 NCW>10	25%
2.	Relationship Between Concepts (RBC)	0 1 2 3 4 the relationship between concepts is unclear	5 6 7 8 9 Clear relationships between concepts	10 The relationship between concepts is very clear and correct.	30%
3.	Branching/ Hierarchical/ Cross-link Relationship BHCR)	0 1 2 3 4 Branching/ hierarchy/ cross-link relationships are written in the concept map quite appropriately.	5 6 7 8 9 Branching/ hierarchical/ cross-link relationships are written in the concept map appropriately.	10 Branching/ hierarchy/ crosslink relationships are written in concept maps very appropriately. Branching/ hierarchy/ crosslink relationships are written in concept maps very appropriately.	30%

No.	Indicators	Criteria and Scoring			Weight
4.	Example (E)	0 1 2 3 4 Equipped with examples written quite precisely (in the form of series/ equations)	5 6 7 8 9 Equipped with examples written correctly (in the form of circuits/ equations)	10 Equipped with examples written very precisely (in the form of series/ equations)	15%
		Category: Score < 6 low 6≤ Score ≤8 medium Score > 8 high			

Problems are given to students to reveal how students solve problems. For more comprehensive information, in-depth interviews were conducted regarding the concept maps created and how students solve problems. The study was conducted on nine second-semester students taking Fundamental Physics II at a private university in Madiun in 2023/2024. Data were collected using assignment documentation, tests, and interviews. The thinking scheme results from triangulation of assignment data (creating concept maps), tests (solving problems), and interviews.

3. Results and Discussion

The results of the research and discussion are presented in two parts: (1) a description of concept map scores and categories and (2) students' thinking schemes for solving problems. The tendency of students' thinking schemes results from representation and triangulation in reviewing students' concept map documents, student assignment completion, and interview results. The description of the results of the research and discussion is as follows:

3.1. Description of Student Concept Map Scores and Categories

The concept maps created by students were scored based on the scoring and categorization guidelines presented in Table 1. The scores and categories of student concept maps are presented in Table 2.

Table 2. Scores and categories of students' concept maps

Initials	NCW	RBC	BHCR	E	Score	Category
Y	10	3	4	2	4.90	Medium
K	10	4	3	3	5.05	Medium
L	10	3	3	2	4.60	Medium
I	10	3	3	0	4.30	Medium
W	10	3	4	0	4.60	Medium
D	10	3	2	0	4.00	Medium
R	10	4	3	1	4.75	Medium
H	10	1	1	0	3.1	Low
RS	10	4	3	3	5.05	Medium

Information: Number of Concepts Written (NCW); Relationship Between Concepts (RBC); Branching/Hierarchical/Cross-link Relationship (BHCR), and Example (E).

Category:

Score < 6 : low

6 ≤ Score ≤8 : medium

Score > 8 : high

Based on Table 2, Students' concept map has two categories, medium and low. The concept maps made by students have not yet achieved a score of more than 8 (high category). The number of concepts all students write is more than 10, the highest achievement indicator. The indicator of providing examples is the lowest indicator achieved. Two students wrote examples with a maximum score of 3 and a minimum of 1. Students' concept maps are effective and easy-to-use tools to evaluate the student's preconceptions and learning results (Llinás et al., 2020). The description of the student concept map is presented based on the student's concept map, the results of the interview explanation, and how students complete the test.

3.2. Students' Thinking Schemes in Solving Problems

Before remedial learning begins, students are asked to create a concept map based on the knowledge they have gained in previous lectures. An example of creating a map has been presented. The time limit for creating a concept map is 60 minutes. After being asked to create a concept map, students are asked to solve the following problems (test): Using the Colorado pheT, create a closed-circuit design consisting of one/two batteries (9V) and three identical lamps (10 ohms) with the following provisions: 1. All three lamps light up equally brightly, 2. One lamp lights up brighter than the others.

The problem can be solved using a CT scheme to obtain optimal results. Problem-solving has a relationship with CT (Limbong et al., 2023). Solving problems will be more effective and efficient when computational thinking is applied. Concept maps are one way to evaluate conceptual knowledge (Joseph et al., 2017). Concept maps allow students to describe a topic conceptually through a concept drawing/sketch, making students visualize knowledge and think carefully (Eachempati et al., 2020). Concept maps can be used to study how students master physics learning, reveal misconceptions, and as a learning evaluation tool (Regita & Yusup, 2024). A structured and complex concept map (high category) shows that students' initial knowledge of the concept is excellent. It is hoped that they can use a computational thinking scheme to solve problems. In general, the computational thinking scheme uses four foundations: (1) decomposition, (2) pattern recognition, and (3) abstraction. (4) algorithm (Figure 1).

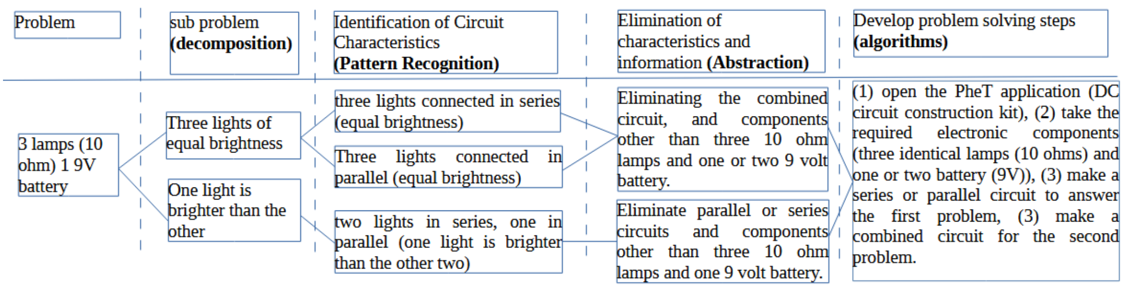
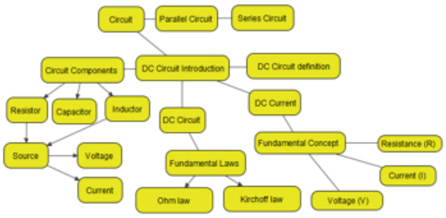
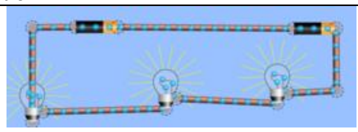
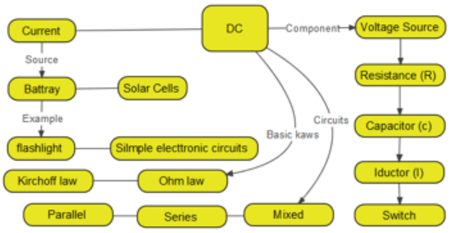
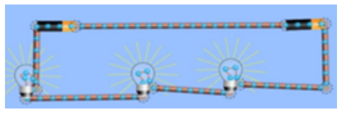
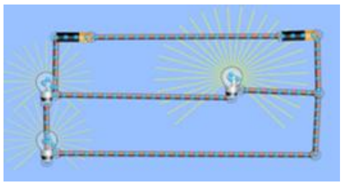
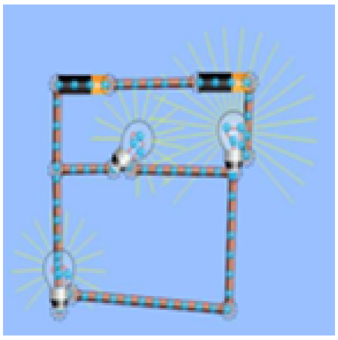
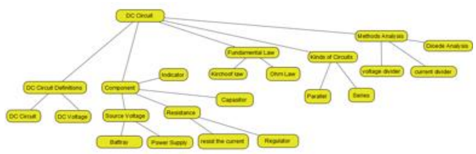


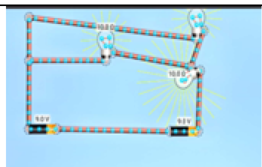
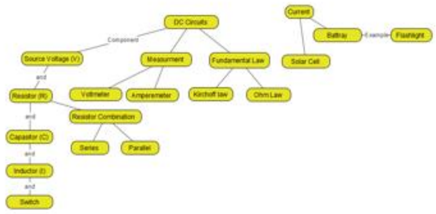
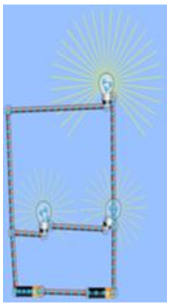
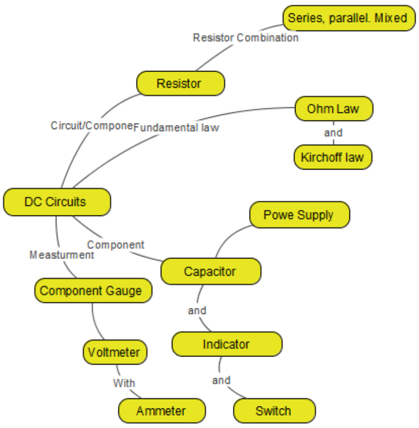
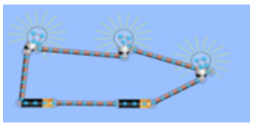
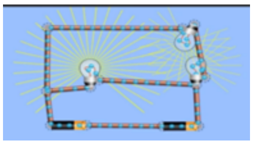
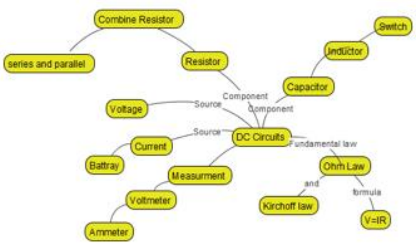
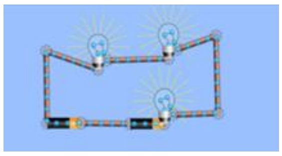
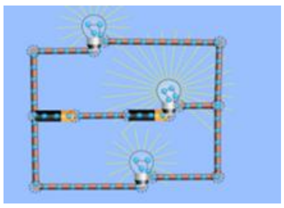
Figure 1. CT Thinking Scheme with Four Foundations

The given problem can be described as two problems: how to make a circuit of (1) three identical lamps (10 ohms) with one battery (9V) that have the same light? (2) one of the lamps lights up brighter than the other lamps with one or two battery sources (9V). This foundation is known as decomposition, simplifying complex problems. The second foundation is to identify the characteristics of the electrical circuit. The three lamps can be connected in series, parallel, and combined in a DC electrical circuit. Three lamps connected in series and parallel can produce the same light brightness. A combined circuit can produce one lamp that lights up brighter than the others. This foundation is called pattern recognition. After pattern recognition (identifying the characteristics of the electrical circuit), the third foundation is to eliminate parts that are irrelevant to the problem. Based on the existing characteristics, problem one can be solved by connecting the three lamps in series or parallel, while problem (2) can be solved with a combined circuit. A 9V battery and three identical lamps (10 ohms) eliminate the voltage and resistance of the lamps with other quantities. This foundation is known as abstraction. The next foundation is to compile the steps of problems 1 and 2. To solve the problem, students use the PhET application Virtual Lab (colorado.edu). The steps are (a) opening the PheT application (DC circuit construction kit), (b) taking the required electronic components (three identical lamps (10 ohms) and one or two batteries (9V)), (c) making a series or parallel circuit to answer the first problem, (d) making a combined circuit for the second problem. This foundation is called an algorithm.

The CT scheme solution will certainly provide an effective and efficient solution, but overall, students tend to use trial and error in obtaining problem solutions. This tendency is linear with the data findings of the concept map category made by students. The concept maps made are in the medium and low categories: the student concept maps and problem solutions (Table 3)(Figure 2-28).

Table 3. Concept map and problem solutions

Initial	Category	Concept Map	Solution
Y	Medium	 **Figure 2. Concept map Y**	 **Figure 3. Solution problem 1**  **Figure 4. Solution problem 2**
K	Medium	 **Figure 5. Concept map K**	 **Figure 6. Solution problem 1**  **Figure 7. Solution problem 2**
L	Medium	 **Figure 8. Concept map L**	 **Figure 9. Solution problem 1**  **Figure 10. Solution problem 2**
I	Medium	 **Figure 11. Concept map I**	 **Concept map 12. Solution problem 1**

Initial	Category	Concept Map	Solution
			 Figure 13. Solution problem 2
W	Medium	 Figure 14. Concept Map W	 Figure 15. Solution problem 1  Figure 16. Solution problem 2
D	Medium	 Figure 17. Concept map D	 Figure 18. Solution problem 1  Figure 19. Solution problem 2
R	Medium	 Figure 20. Concept map R	 Figure 21. Solution problem 1  Figure 22. Solution problem 2

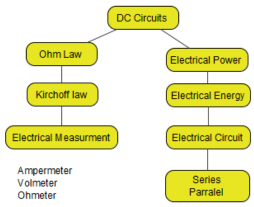
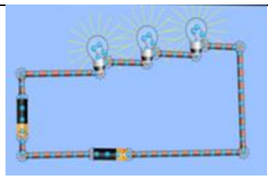
<table>
<tr><th>Initial</th><th>Category</th><th>Concept Map</th><th>Solution</th></tr>
<tr><td>H</td><td>Low</td><td>

Figure 23. Concept map H</td><td>
Figure 24. Solution problem 1

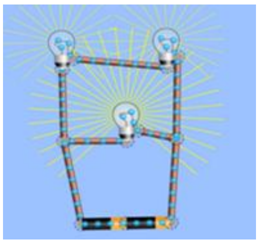



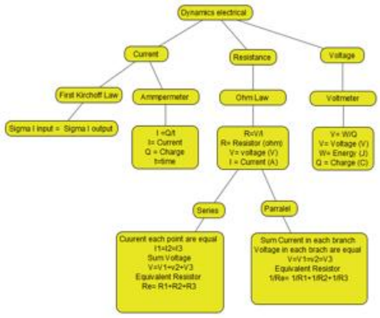
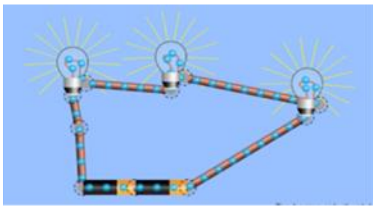
Figure 25. Solution problem 2</td></tr>
<tr><td>RS</td><td>Medium</td><td>

Figure 26. Concept map RS</td><td>
Figure 27. Solution problem 1

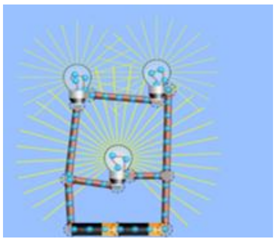



Figure 28 Solution problem 2</td></tr>
</table>

Constructing concept maps with good levels of hierarchy and concept relationships (high category) allows for significant learning. It can potentially develop conceptual abilities and understanding and relate them to existing preconceptions (Hernández-Suárez et al., 2020). Based on the results of tables 2 and 3, eight students have a medium concept map category, and one student is in the low category. Student Y (medium category) has a different answer response from the others. Solution problem 2 (Figure 4): one of the lamps is not connected to the cable. At first glance, the lamps look connected in series, so there is no difference between the solutions to problems 1 and 2. Student Y can describe Kirchhoff's law and Ohm's law well and can exemplify the application of AC and DC circuits but has not been able to explain the difference between AC and DC voltage phase diagrams based on the results of the concept map interview—the results of the interview related to the assignment. Student Y said that initially, he tried to assemble and obtain the circuit, as shown in Figure 4. Student Y just realized that one of the lamps was off. It was also conveyed that one of the lamps was brighter than the others because the lamp was directly connected to the battery, while the other was divided. Problem 1 was obtained directly (by trial and error). It lights up the same because the flow (current flow) is in the same direction (student Y argument). Student Y said that the difference between circuits 1 and 2 was that the circuit (cable) for problem 1 was straighter than problem 2, which had more bends, which caused a difference in the brightness level of the lights.

Referring to the arguments presented by the students, although they had received electrical material (series and parallel circuits) in the previous meeting, the tendency to use trial and error in finding solutions and intuition in arguing was more dominant. The knowledge that should be possessed related to the characteristics of series, parallel, and mixed circuits was not used as the basis for argumentation (scientific argumentation). Based on the student Y concept map, the concept of series and parallel circuits was written, but the relationship and branching lines were unclear. Student Y also did not provide examples of series and parallel circuits, so student Y potentially lacks knowledge about the concept.

Nonscientific intuitive knowledge can directly influence problem-solving activities (Sherin, 2006). Solutions may be obtained (using trial and error and intuition), but the knowledge gained is potentially wrong or nonscientific. Students with a lack of knowledge of the concept have the potential to use trial and error and intuition in solving problems and arguments. The trial and error method of solving shows that students lack knowledge of the concept. This uncertainty stimulates students to experiment using trial and error until a solution is found. Finding a solution becomes new knowledge for students, but it does not mean the knowledge (obtained) is scientific. Intuition impacts nonscientific arguments in the interview results. The non-CT 1 thinking scheme is used by students (see Figure 29).

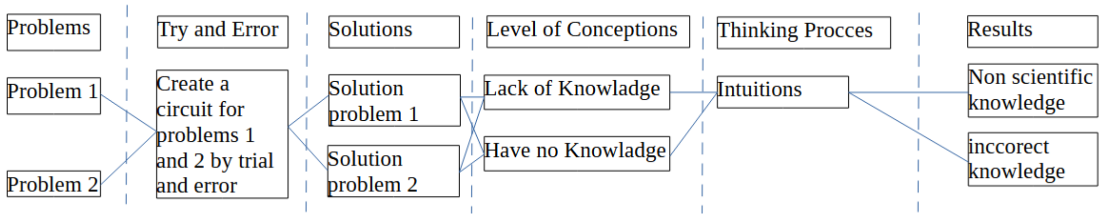


Figure 29. Non CT1 scheme 1 (General non-CT)

Lack of knowledge of the concept has the potential to produce nonscientific knowledge. Ontological confusion (from lack of knowledge) and analytical thinking coexist with nonscientific intuitive forms of thought (Impey et al., 2012). Problem-solving with the trial and error model is effectively used to prove concepts or test hypotheses. Knowing the concept (characteristics of electrical circuits and parallels) will provide an effective solution to solving problems using CT. Using trial and error (non-CT) takes longer to get the solution. It could be the second, third, and others.

Student L created a concept map and wrote examples of series and parallel circuits on the concept map (Figure 8). The concept map created by student L has unclear relationships and branching lines; examples of depictions of series and parallel circuits are not yet accurate. Based on information from the concept map (moderate category) created, students lack knowledge about the concept. The tendency of students to use trial and error in solving problems is higher. The results of the interview with student L realized the mistake in writing examples of series and parallel circuits. In obtaining a solution to problem 1, student L could immediately answer because the current is the same, so the three lights will light up equally brightly. Student L solve problem 2 using trial and error. The interviewer asked: "If all the lights are in parallel, are the lights of the three lights different or the same?". The student's response to the question was "different". Based on the interview, students have a conception that three lights arranged in series will produce the same light brightness, arranged in parallel will produce different light brightness. The combined thinking scheme (CT and non-CT) (see Figure 30).

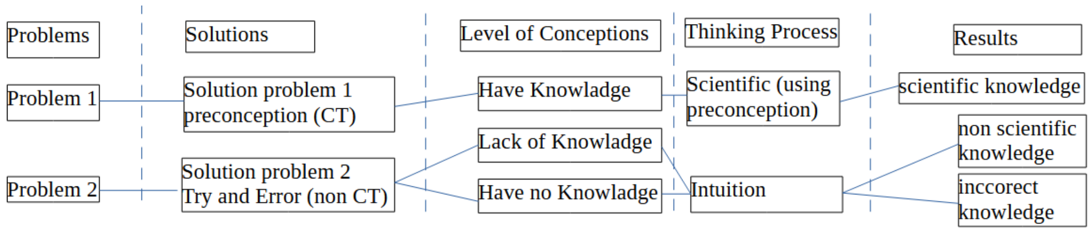


Figure 30. A combined CT and non-CT scheme

The combined CT and non-CT thinking scheme (Figure 30) provides information that students who know certain concepts will use CT and scientific thinking processes to solve problems. Effective and efficient solutions are produced by a good understanding of the problem (Handayani et al., 2023). Knowledge of concepts is an important thing that must be possessed in implementing CT to solve problems. This will help students to understand the problem without missing important information. The solution using non-CT or a combination can be correct, but the knowledge obtained from each process can be wrong, nonscientific, or both.

Student H created a concept map in a simple hierarchy and wrote down series and parallel electrical circuits (without their characteristics). The interview results with student H provided information that students have an incorrect conception related to series and parallel circuits. Students do not know about resistors arranged in combination (series and parallel). Students think that the lamp circuit arranged in Figure 24 is parallel, and the lamp circuit arranged in Figure 25 is parallel. The tendency of students not to know the concept is supported by the results of the concept map created, where many unrelated concepts are directly connected without explanation. The concept map created is in the low category. The non-CT 2 thinking scheme (Figure 31).

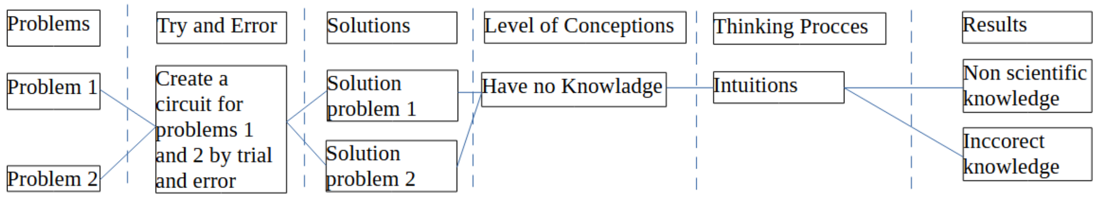


Figure 31. Non-CT 2 thinking scheme

The non-CT 2 thinking scheme (Figure 31) is difficult/rarely found, considering that students ideally know or at least lack knowledge of the concept. The finding that students lack knowledge is possible because students cannot recall their preconception knowledge. From the non-CT 1, CT 2, and combined (CT and non-CT) schemes, trial and error and intuition are characteristics in finding solutions and drawing conclusions. Knowing the concept is a fundamental foundation for implementing CT. Decomposition, pattern recognition, and abstraction require knowledge of the concept to obtain effective, efficient, and optimal solutions. This research found no students who made concept maps with a high category (score > 7). The CT (ideal) thinking scheme cannot be described thoroughly, considering that the qualitative data does not support it.

4. Conclusion

Students' conceptual knowledge is essential in determining the students' thinking scheme in solving problems. In electrical circuit problems (series, parallel, and combined), students with little or no knowledge of the concept tend to solve problems without CT (non-CT). Problem-solving solutions may be obtained by using trial and error, but it should be remembered that there are inherent impacts related to the new knowledge obtained by students. The nature of the latest knowledge obtained by students leads to false knowledge, nonscientific knowledge, and even both. Concept maps are recommended as one way to reveal students' preconceptions. The preconceptions they have, learning outcomes, and their outcomes can be used as material for reflection and evaluation of subsequent learning. At least, students' thinking schemes, CT, non-CT, and combined, can provide initial information for facilitators about the importance of strengthening concepts in the learning process.

This research has not revealed students who create concept maps in the high (ideal) category and good conceptual knowledge (based on data results). Recommendations for future research can be conducted using the same material or different ones to support the results obtained. Modifications to the thinking scheme can also still be developed based on the findings obtained in further research. New findings from the CT and non-CT thinking schemes show that non-CT tends to use trial and error in determining solutions and intuition in conclusion. This research is limited to the subjects that have been determined. Other results may be different considering the conception and level of knowledge possessed by students (as subjects) are different. Special cases may be found in students who have good knowledge of concepts, but tend to use trial and error (non-CT) in solving problems.

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