A Study of Grade Eleven Student's Representations of Electricity Through Model-Based Inquiry

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Abstract

The COVID-19 pandemic forced schools to close and transition online. The authors are interested in whether students have a higher level of representation after learning via an online learning platform through the Model-Based Inquiry (MBI) method and how they can be supported. This study took place in a school in a western province of Thailand, with thirty-two students studying in grade eleven. The study was conducted in an online classroom, implementing an action research strategy with two action research loops. The first loop consisted of three lessons, followed by another three lessons in the second loop, all aimed at improving the students' representations. To collect data, a representation test was used after both loop one and loop two implementations. The students' representations were then interpreted and grouped into five levels. The quality of each answer was assessed using criteria which included fair, good, and very good categories. The results demonstrated that students' representations were enhanced through model-based inquiry. There was a noticeable improvement in the students' representations from loop 1 to loop 2 of the action research at all three levels, consisting of the macroscopic level, microscopic level, and symbolic level.

Introduction

Physics is an abstract subject that studies matter and energy and is concerned with how they relate to each other. This relationship is fundamentally represented in mathematical language, and physicists use mathematical modeling to predict the behavior of natural systems. In teaching physics, formulas and graphs are used to represent abstract concepts which are then transformed into concrete representations such as physical models and analogies, as explained by Feynman (1994). However, these representational transformations can also lead to significant problems in the learning process, as a particular representation might add or leave out information, thereby changing the meaning of other representations used to explain a certain concept (Treagust, 2017). To help students explain concepts more clearly, they need to understand the content at three different levels:

Macroscopic level, which presents observable phenomena, such as being able to describe the model of connecting batteries in an electric circuit.

Microscopic level, which presents things that are invisible to the naked eye in the form of models or other visual displays, such as imagining the movement of electric charges and electrons in an electric circuit, etc.

Symbolic level, which involves the use of symbols, numbers, letters, or signs (Jaber, 2012).

By comprehending concepts at these three levels, students can gain a deeper understanding of physics.

Generally, learning about electricity is a challenging aspect of physics. It appears invisible and proves to be very abstract and complex for students to grasp fully. Concepts like current, magnetic fields, and forces can be difficult to model and understand. Consequently, physics classrooms should provide students with opportunities to create representations of these ideas on multiple levels, enabling them to communicate their understanding effectively to their teachers. Regular assessments of students' ideas during class can aid in improving their level of representation. When multiple representations are used for teaching, it is expected that students will experience more successful learning outcomes. To ensure this, investigations should be carried out to assess the impact of these implementations on student learning and classroom communication (Treagust, 2017). An inquiry-based approach to knowledge acquisition, testing, and model revision is known as model-based inquiry or MBI (Windschitl, 2008). This teaching approach has been widely accepted by researchers, as it focuses on linking concepts, scientific processes, the nature of science, and communication, significantly enhancing science learning (Neilson, 2010). Numerous researchers have demonstrated that model-based inquiry can support students in improving their representations and encourages them to create scientific explanations (Kratumnok, 2019). The COVID-19 pandemic in 2019 forced schools to close and transition to online instruction to prevent the transmission of the coronavirus among students (Bayham, 2020). The COVID-19 pandemic in 2019 forced schools to close and transition to online instruction to prevent the transmission of the coronavirus among students (Bayham, 2020). Responding to the COVID-19 pandemic, UNESCO recommended distance learning programs and open educational applications during school closures. Online instruction has become a solution to keep learning activities uninterrupted (Wayo, 2020). Therefore, the authors are interested in whether students have a higher level of representation after learning via an online learning platform through the Model-Based Inquiry (MBI) method, and how they can be supported.

Methodology

This study occurred in a secondary school in a western province of Thailand. Thirty-two grade eleven students participated in this study. We designed online classrooms using the online platform www.zoom.us, as the research was conducted during the COVID-19 pandemic. Additionally, we utilized simulations from www.phet.colorado.edu to design models for teaching and learning. The data was collected using the following data tools.

The lesson plans.

This action research consisted of two loops, with each loop comprising 3 online lesson plans, each lasting 2 hours. In total, there were six online lesson plans, as shown in Table 1.

Table 1. Lesson plans and class hours in two loops of action research.

Lesson plans			
Loop 1	**Hours**	**Loop 2**	**Hours**
Lesson 1) Ohm's law	2	Lesson 4) electrical energy and potential difference	2
Lesson 2) electric resistivity and conductivity	2	Lesson 5) electrical energy and electric power	2
Lesson 3) resistor connection	2	Lesson 6) battery connection	2

Every online lesson plan is constructed based on the Model-Based Inquiry (Windschitl, 2008), encompassing all three levels: macroscopic, microscopic, and symbolic. The three levels of representation on electricity were incorporated during the classroom activity in every lesson plan, following the diagram in Figure 1.

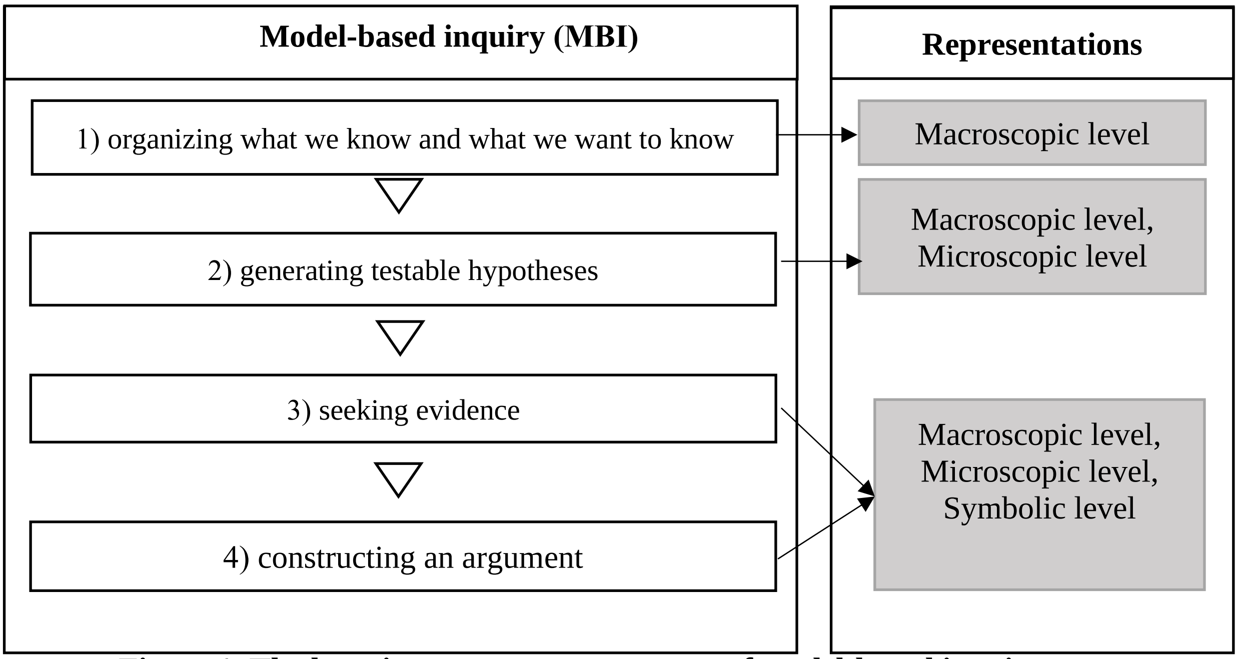


Figure 1. The learning management process of model-based inquiry.

The representation types on electricity

1. Macroscopic level, which is a presentation of observable phenomena such as batteries in an electric circuit and lamp brightness.
2. Microscopic level, which involves presenting invisible things that are not visible to the naked eye in the form of models or other visual displays. For example, imagining the movement of electric charges and electrons in an electric circuit, etc.
3. Symbolic level, which involves the use of symbols, numbers, letters, or signs, such as using arrows to show electron movement and electric current.

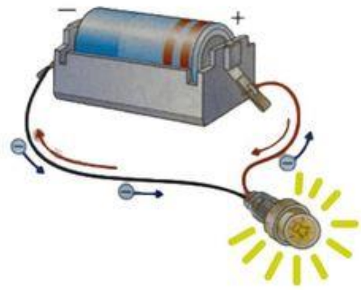
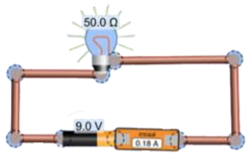
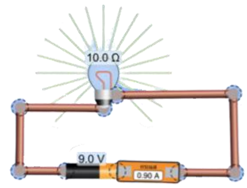
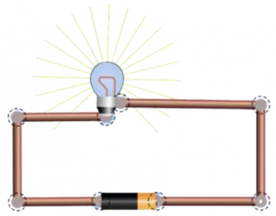


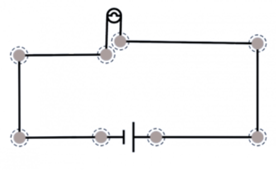
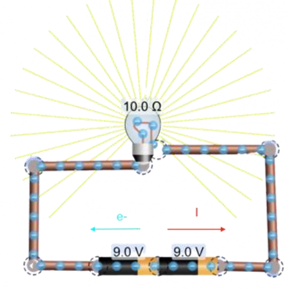
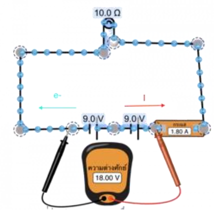
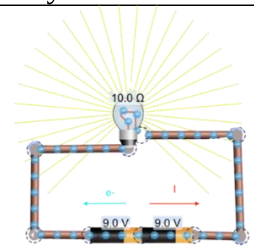
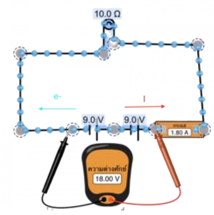
Figure 2. The representation on electricity applied from Sakai (2018).

The pictures and explanations of the connecting circuit in the simulation represented the observable phenomena, such as the model of connecting batteries in an electric circuit, which is at the Macroscopic level shown in every step of the Model-Based Inquiry (MBI). The pictures and explanations depicted things that are invisible to the naked eye in the simulation. They were presented in the form of models or other visual displays, such as imagining the movement of electric charges and electrons in an electric circuit, etc., shown in steps 2-4 of the Model-Based Inquiry (MBI). Additionally, symbolic representations, such as symbols, numbers, letters, or signs, were shown in steps 2, 3 and 4 of the Model-Based Inquiry (MBI).

Examples of lessons on electric energy and electric power, based on the Model-Based Inquiry (MBI), are presented in Table 2.

Table 2. Example of a lesson plan for the electric energy and electric power lesson, based on Model-Based Inquiry

Steps	Representations
1) Organizing what we know and what we want to know The teacher asked questions about how to choose the lamp: which one of the lamps will give the most brightness, the one with more electric power (watts), or the one with less electric power (watts)? Next, the teacher demonstrated the experiment using the simulation and the students recorded the observable phenomena and results of the experiment in the student worksheet.	 1.62-watt  macroscopic level
2) Generating testable hypotheses The teacher led the students to generate hypotheses about which variables affect the electric power of the circuit. Then, the teacher demonstrated the replacement of observable phenomena in the electric circuit, which is at the macroscopic level, with the use of symbols, which is at the symbolic level. The students completed the activity worksheet.	 macroscopic level

Steps	Representations
	 symbolic level
3) Seeking evidence The teacher asked the students to test their hypotheses. Then, the teacher demonstrated the linking of representations at different levels: macroscopic level, such as the brightness of the lamp; microscopic level, such as the flow of electrons affecting the brightness of the lamp; and symbolic level, such as electrical circuit symbols. The students learned about electric energy and electric power and completed the activity worksheet.	 macroscopic level, microscopic level  microscopic level, symbolic level
4) Constructing an argument The teacher led the students in a discussion about electric energy and electric power. After that, the teacher showed all levels of representations again and asked questions to check the students' understanding of the three levels of representations. Then, the students recorded their answers on the worksheet.	 macroscopic level, microscopic level  microscopic level, symbolic level

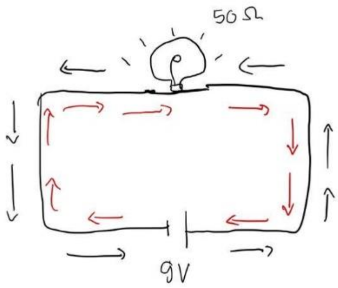
Example of student's worksheet.

The student's worksheet was used to record students' representations during each activity. The worksheet contains four scenarios arranged step by step, following the model-based inquiry corresponding to Figure 1. An example of Scenario No. 4 in the student worksheet for the electric energy and electric power lesson, is shown in Figure 3.

Example of student's worksheet.

Draw a model of an electric circuit consisting of a lamp with 50 ohms of resistance and a 9 volt battery. Show the movement of electron flow in the electric circuit.
Calculate the current and electric power of the circuit.

scenario and instruction



Students show the representations of electrical circuits related to the scenario.

Explain (calculate)

$$P = \frac{V^2}{R}$$

$$P = \frac{9^2}{50}$$

Summarize the relationship between electric power, potential difference, resistance, and electric current.

ค่ากำลังไฟฟ้า ขึ้นอยู่กับ ค่ากระแสไฟฟ้า,
ค่าความต่างศักย์ และค่าความต้านทาน

The electric power depends on the current, the potential difference, and the resistance.

Students explain their understanding of the concept of electrical circuits.

Figure 3. Show an example of student's worksheet.

The representation tests.

There were two representation tests, each consisting of three scenarios, used to collect students' representations after loop 1 and 2. Every scenario of the representation test consists of three components: scenario, instruction, and explanation. The difference for each scenario lies in the explanation, which consists of calculations based on the conditions of the problem and an explanation of the content related to the subtopics of electricity. An example of a scenario from the representation test is shown in Figure 4.

Scenario 1: A student wants to light up the lamp by connecting a 9-volt battery, a 10-ohm resistor, and a wire with the lamp. He found that the lamp was bright. Now, he wants to conduct more experiments and decides to use four 9-volt batteries connected in series. What will happen to the lamp?

Instruction: show the differences between the two electric circuits.

Circuit 1: a battery	Circuit 2: four batteries connected in series
Circuit diagram	Circuit diagram
Potential difference	
Electric current	
Explain	

Figure 4. Example of a scenario in the representation test.

Data collection

This research was implemented using the action research strategy, with two action research loops. Each loop consisted of three lessons, aimed at improving students' representations.

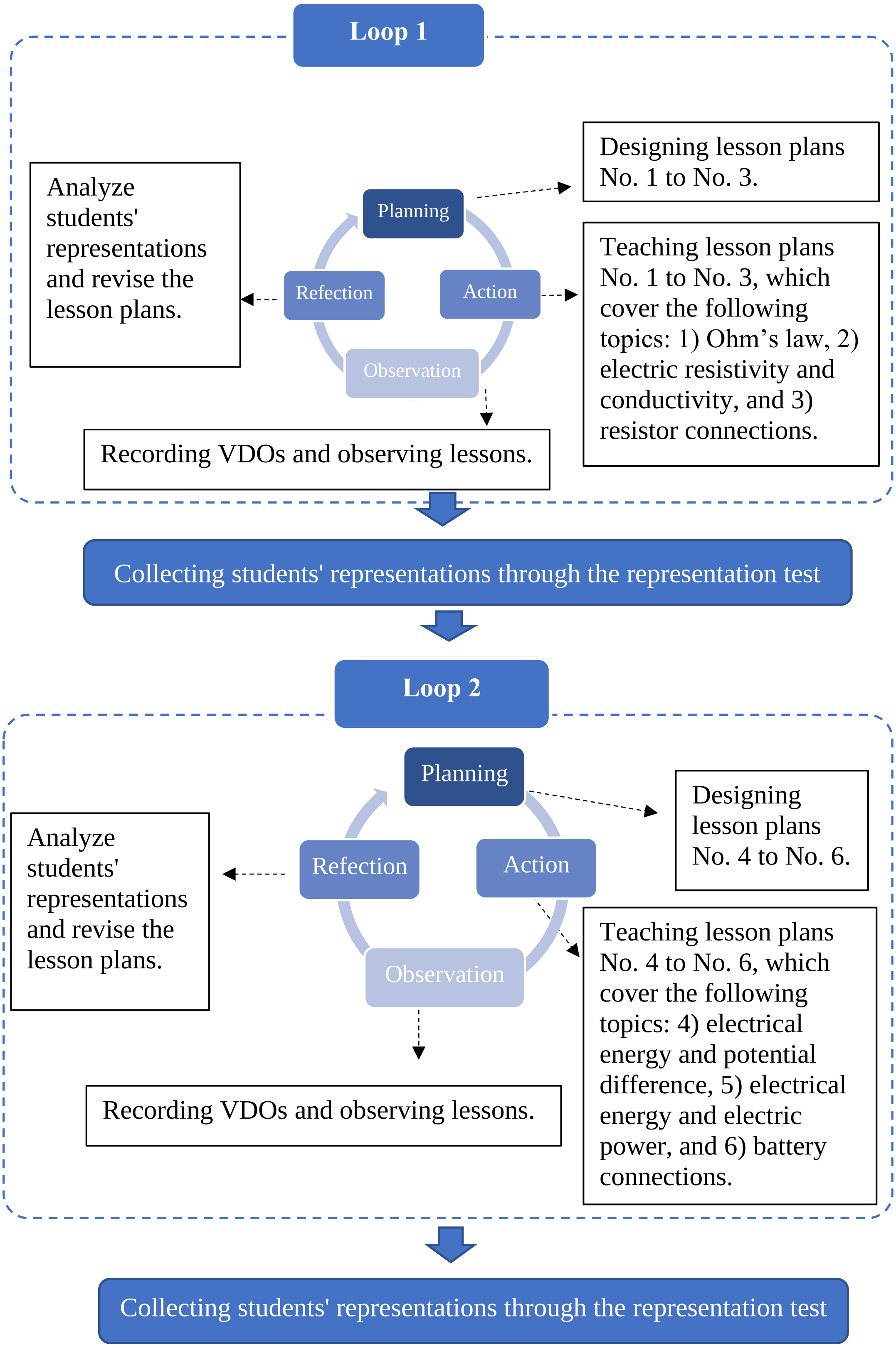
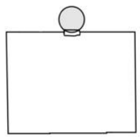
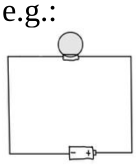
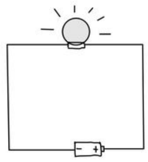
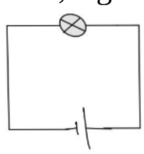
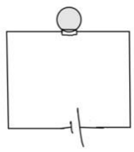
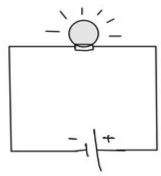
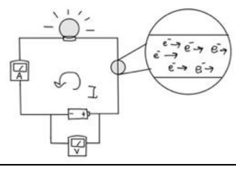


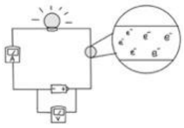
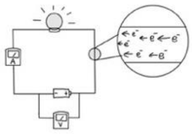
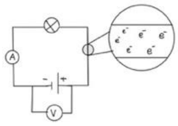
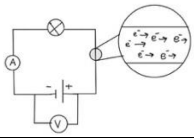
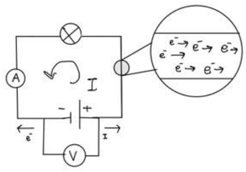
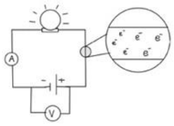
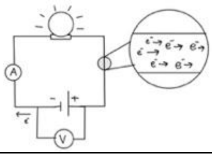
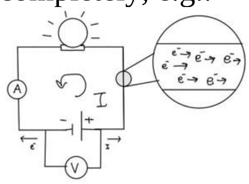
Figure 5. Diagram of data collection process.

Data analysis

The data from the students' representation test, which was used after loop 1 and after loop 2, were analyzed based on the criteria of the contents, consisting of 3 levels: macroscopic level, microscopic level, and symbolic level (Jaber, 2012). The students' representations were classified into 5 levels according to (Kozma, 1997). Additionally, the students' ideas were grouped based on the quality of their representations using three criteria: fair, good, and very good, as defined by Wang (2007).

Table 3. Shows the representational competence levels of the electricity.

Level of Representation	Characteristics	Quality		
		Fair	**Good**	**Very good**
1) Representation as Depiction.	Students show macroscopic level of representations to describe physical phenomena.	Able to represent at the macroscopic level but not correct, e.g.: 	Able to represent macro-level accurately but not completely, e.g.: 	Able to represent macro-level accurately and completely, e.g.: 
2) Early Symbolic Skills	Students show macroscopic level and symbolic level of representations to describe physical phenomena.	Not able to represent at the macroscopic level and symbolic level or able to represent only at the symbolic level, e.g.: 	Able to represent at the macroscopic level and symbolic level accurately but not complete, e.g.: 	Able to represent macro-level and symbolic level accurately and completely, e.g.: 
3) Syntactic Use of Formal Representations	Students show macroscopic level and microscopic level of representations to describe physical phenomena.	Not able to represent at the macroscopic level and microscopic level or able to represent only at the microscopic	Able to represent at the macroscopic level and microscopic level accurately but not completely, e.g.:	Able to represent macroscopic level and microscopic level accurately and completely, e.g.: 

Level of Representation	Characteristics	Quality		
		Fair	Good	Very good
		level, e.g.: 		
4) Semantic Use of Formal Representations	Students show symbolic level and microscopic level of representations to describe physical phenomena.	Able to represent at the microscopic level and symbolic level but not correct, e.g.: 	Able to represent at the microscopic level and symbolic level accurately but not completely, e.g.: 	Able to represent microscopic level and symbolic level accurately and completely, e.g.: 
5) Reflective Rhetorical Use of Representation	Students show macroscopic level symbolic level and microscopic level representations to describe physical phenomena.	Able to represent at the macroscopic level, microscopic level and symbolic level but not correct, e.g.: 	Able to represent at the macroscopic level, microscopic level, and symbolic level accurately but not completely, e.g.: 	Able to represent macroscopic level, microscopic level, and symbolic level accurately and completely, e.g.: 

Results

The data was collected through the representation test after loop 1 and loop 2, following the action research strategy with two action research loops, three lessons in loop one, and three lessons in loop 2. The results of grade 11 students' representations on electricity through model-based inquiry are summarized in Table 4

Table 4: Percentages of students in each representational competence levels, on the electricity topic representation test.

lessons	Level of student's representation														
	Level 1			Level 2			Level 3			Level 4			Level 5		
	fair	good	Very good	fair	good	Very good	fair	good	Very good	fair	good	Very good	fair	good	Very good
	The percentages of students in loop 1														
Scenario1: Ohm's Law				**53**	**47**										
Scenario2: Resistivity and conductivity				**38**	**9**	**53**									
Scenario3: Resistor connecting				**59**	**6**	**35**									
	The percentages of students in loop 2														
Scenario4: Electrical energy and potential difference							**47**	**31**	**22**						
Scenario5: Electrical energy and electric power							**53**	**25**				**22**			
Scenario6: Battery connecting							**53**	**16**				**31**			

From Table 4, it can be observed that in loop 1, the students' representations of electricity through model-based inquiry showed the best performance group in all scenarios (scenario 1 to scenario 3) at level II. Scenario 1 exhibited good quality, while both scenario 2 and scenario 3 showed very good quality in the representations test. The students demonstrated early symbolic skills, where they used both macroscopic level and symbolic level representations to describe physical phenomena. In the good quality on level II, students were able to represent accurately at the macroscopic level and symbolic level but not completely according to the conditions of the problem, and they provided explanations based on the subtopics of electricity. On the other hand, in the very good quality on level II, students were able to represent accurately and completely at the macroscopic level and symbolic level, according to the conditions of the problem, and provided explanations based on the subtopics of electricity, as shown in scenario 3. However, the representational competence levels of students' representations of electricity through model-based inquiry in loop 1 were unable to show the microscopic level, which presents things that are invisible to the naked eye in the form of models or other forms of presentations that can be visible displays, such as imagining the movement of electric charges and electrons in an electric circuit, etc.

Following the action research method, action research was applied to improve specific practices based on action, evaluation, and critical analysis of practices using collected data to introduce improvements in relevant practices.

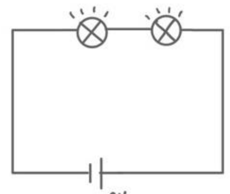
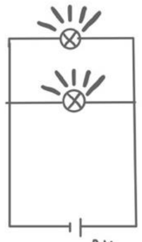
Therefore, in loop 2, the teacher improved the strategy by presenting representations of electricity at the microscopic level. This involved explaining phenomena both visible and invisible to the naked eye, using models to illustrate the movement of electric charges and electrons in an electric circuit, and so on. For example, the teacher created a question that led students to link the brightness of the lamp, which is at the macroscopic level, to the movement of electrons, which is at the microscopic level, in the circuit. The teacher demonstrated this relationship using a circuit simulation in step 3 of the MBI method, seeking evidence. As a result, students displayed representations of all three levels: macroscopic, microscopic, and symbolic, in step 4 of the MBI method while constructing an argument.

Therefore, the data in loop 2 showed that the students' representations of electricity through model-based inquiry had improved. The best performance group of students in scenario 4 demonstrated 22% of representational competence at level III with very good quality, while the best performance group of students in scenarios 5 and 6 showed 22% and 31% of representational competence at level IV with very good quality. In the very good quality on level III, students were able to represent the macroscopic and microscopic level accurately and completely, according to the conditions of the problem, and provided explanations based on the subtopics of electricity. Similarly, in the very good quality on level IV, students were able to represent the microscopic level and symbolic level accurately and completely, according to the conditions of the problem, and provided explanations based on the subtopics of electricity, as shown in scenario 6. These improvements were evident from loop 1, where students demonstrated the semantic use of formal representations, showing both microscopic level and symbolic level representations to describe physical phenomena.

The example of the students' representation in the representation test after loop1.

Scenario: Students want to conduct an experiment comparing resistor connecting patterns. They have two lamps, a 10-ohm resistor, wires, and a battery with a 9-volt potential difference. The students perform two experiments: circuit 1, where the lamp is connected in series, and circuit 2, where the lamp is connected in parallel. They want to observe the difference in brightness between the two lamps.

Instruction: Compare the differences of two electric circuits.

<table>
<tr><td>Circuit 1: connect lamp in series</td><td>Circuit 2: connect lamp in parallel</td></tr>
<tr><td>Circuit diagram

</td><td>Circuit diagram

</td></tr>
<tr><td colspan="2">Resistance
$R_{รวม} = R_1 + R_2$
$R_{รวม} = 10 + 10$
$\therefore R_{รวม} = 20$ โอห์ม
$\frac{1}{R_{รวม}} = \frac{1}{R_1} + \frac{1}{R_2}$
$\frac{1}{R_{รวม}} = \frac{1}{10} + \frac{1}{10}$
$\therefore R_{รวม} \quad \frac{2}{10} = \frac{1}{5}$ โอห์ม</td></tr>
<tr><td colspan="2">Explain
การต่อตัวต้านทานแบบอนุกรมค่าความต้านทาน (R) จะมากกว่า
การต่อแบบขนาด ทำให้หลอดไฟสว่างน้อยกว่า
The resistance (R) of a resistor connected in series is greater than when connected in parallel. This causes the brightness of the lamp to be lower than the other one.</td></tr>
</table>

In the scenario Resistor Connecting, the students showed their representations as follows:

Macroscopic level: Students presented the observable phenomena by showing differences in brightness between both circuits of lamps. They also explained the reasons for the difference in lamp brightness, relating it to the calculations at the symbolic level.

Symbolic level: Students used symbols, such as the symbol of a battery, symbol of a wire, and symbol of a lamp, to draw the electrical circuit. They also included the calculations based on scenario conditions.

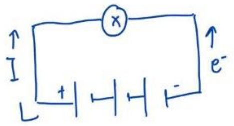
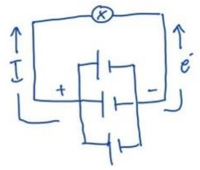
In very good quality on level III, students were able to represent the macroscopic level and microscopic level accurately and completely, according to the conditions of the problem. They also provided explanations based on the subtopics of electricity related to resistor connecting.

The representative data of loop 1 in table 4 was shown that the best performance group of students comprising 35% of the students at level II of the representation criteria with a very good quality of representations. These students demonstrated early symbolic skills by depicting both macroscopic and symbolic level representations to describe physical phenomena. At the macroscopic level, students accurately depicted electrical circuits based on the given situation, showing the differences in lamp brightness when connected in series and parallel patterns. At the symbolic level, students correctly performed calculations involving various variables from the given conditions. However, the conclusion for loop 1 was that none of the students showed representations at the microscopic level.

The example of the students' representation in the representation test after loop2.

Scenario: A scientist wants to conduct an experiment to compare how the battery connection pattern in the circuit affects the brightness of a lamp. They will use a 10-ohm resistor, wires,

and three batteries with a 9-volt potential difference, connected in both series and parallel. The goal is to observe the brightness difference between the two lamps.
Instruction: Compare the differences of two electric circuits.

<table>
<tr><td>Circuit 1: connect batteries in series</td><td>Circuit 2: connect batteries in parallel</td></tr>
<tr><td>Circuit diagram

</td><td>Circuit diagram

</td></tr>
<tr><td colspan="2">Potential difference
$V_{รวม} = V_1 + V_2 + \dots$
$= 9 + 9 + 9$
$V_{รวม} = 27$ V. ※
$V_{รวม} = V_1 = V_2 = V_3$
$V_{รวม} = 9 = 9 = 9$ ※</td></tr>
<tr><td colspan="2">Electric current
$I_{รวม} = I_1 + I_2$
$I_{รวม} = \frac{V}{R} = \frac{27}{10} = 2.7$ A. ※
$I_{รวม} = I_1 + I_2$
$\frac{V}{R} = 0.9$ A. ※</td></tr>
<tr><td colspan="2">Explain
กระแสไฟฟ้า วงจร อนุกรม มากกว่า วงจรขนาน เพราะ ความต่างศักย์รวม ของวงจร อนุกรม มากกว่า วงจรขนาน.

The current of connecting battery in series is greater than the connecting battery parallel circuit. Because the total potential difference of the series circuit is higher than in parallel circuit.</td></tr>
</table>

From the scenario Battery Connecting, the student showed the following representation: 1) Symbolic level: The student used symbols such as the battery, wire, and lamp to draw the electrical circuit. They were also able to calculate variables according to the scenario. 2) Microscopic level: The student presented invisible phenomena in the form of models, showing the movement of electric charges and electrons in the electric circuit. At the very good quality on level IV, the student was able to represent both the microscopic and symbolic levels accurately and completely according to the given conditions and explain the content of the scenario based on subtopics of electricity, which is Battery Connecting.

In the representative data of loop 2 in table 4, it was shown that the best performance group of students consisted of 31% of the students in level IV of the representation criteria, demonstrating very good quality representations. Students showed a semantic use of formal representations, meaning they showed symbolic level and microscopic level representations to describe physical phenomena. At the symbolic level, students accurately depicted electrical circuits using circuit symbols based on the given situation, and they correctly performed calculations of various variables from the conditions provided. At the microscopic level, students demonstrated an understanding of the motion of electron flow and electric current.

The data indicated that in loop 2, the students were able to show representations at a higher level compared to loop 1. Consequently, the students were able to represent all levels of representations, including macroscopic level, symbolic level, and microscopic level representations, to describe electricity after learning through model-based inquiry.

Conclusion and Discussion

Do students have a higher level of representation after learning via an online learning platform through the Model-Based Inquiry (MBI) method, and how can they be supported? Data from loop 1 showed that the students were able to show macroscopic level and symbolic level representations to describe physical phenomena but were unable to show representations at the microscopic level. The data indicated that the best performance group of students in all scenarios (Scenario 1 to Scenario 3) were at level II. Based on the conclusion drawn from loop 1, improvements were made to the lesson plans in loop 2, following the action research strategy. In loop 2, the teacher improved the strategy by presenting representations of electricity at the microscopic level, involving invisible phenomena not visible to the naked eye, in the form of models, such as the movement of electric charges and electrons in an electric circuit, etc. Afterward, the students completed representation worksheets, where they had to show connections between all levels of representation about electricity, including the macroscopic level, microscopic level, and symbolic level. For example, the teacher created a question that led students to link the brightness of the lamp which is at the macroscopic level to the movement of electrons which is at the microscopic level. The teacher demonstrated this relationship using a circuit simulation in step 3 of the MBI method, seeking evidence. As a result, students displayed representations of all three levels: macroscopic, microscopic, and symbolic in step 4 of the MBI method while constructing an argument. The data from loop 2 shows that the students were able to show representations at all levels to describe electricity after learning through model-based inquiry. However, students had difficulty in associating all representations at the macroscopic, symbolic, and microscopic levels. The best performing group of students in Scenario 4 showed 22% of representational competence at level III with very good quality, and the best performing groups in Scenario 5 and 6 showed 22% and 31% of representational competence at level IV with very good quality, respectively. These results indicate that model-based inquiry was able to improve the level of students' representation from level II with very good quality to level IV with very good quality, effectively describing electricity, even in an online classroom. Students showed a higher level of understanding of the concept of physics when studying electricity through model-based inquiry (MBI) in loop 2.

Students' representations were improved by teacher guidance based on the Model-Based Inquiry (MBI) method. The study demonstrates the usefulness of examining students' knowledge and the use of representations during lessons to enable effective teacher responses. Furthermore, the study highlights the significance of instructional guidance by the teacher to help improve students' learning by seeking their representations during classroom activities. This approach is deemed very important for student development.

Suggestions

In the next study, the researchers should focus on increasing the interest from a physics didactic point of view and improving the quality of all representations at the macroscopic level, symbolic level, and microscopic level. For example, colors could be used to represent potential, the thickness of current arrows could indicate current intensity, the length of voltage arrows could show potential difference, and the height of columns could represent energy, among other possibilities.

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