Explaining and enacting for conceptual understanding in secondary school physics

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This paper reports on a study of pedagogical strategies for promoting conceptual understanding by reducing misconceptions. The case chosen to investigate this phenomenon involved 40 Thai vocational education students studying physics (electric circuits) in secondary school. The study investigated the effect of an explaining strategy on students' understanding. It also investigated the effect of an enacting strategy on students' overall misconceptions with one group (n=20) using an electric circuits board (CB) whilst another group (n=20) used a virtual simulation (VS) of electric circuits. Pre- and post-test results showed significant improvements in understanding. Pre- and post-test results for the 'enacting' strategy comparing the virtual simulation versus the electric circuits board showed significant increases within groups, as well as a significant reduction in misunderstanding for the VS group. However, the overall levels of misunderstanding remained high in spite of the significance of the intervention. This result confirms the characterisation of misconceptions as persistent difficulties. Implications point to the value of combining multiple strategies for conceptual understanding, matching strategies to the context and to the limitations of evaluating conceptual understanding.

Introduction

Conceptual understanding is an important goal in learning in general but is particularly relevant in science education because such understanding is required to make sense of phenomena. To understand involves being able to construct meaning, to interpret and explain (Anderson et al., 2001). It involves understanding "of the principles that govern a domain and of the interrelations between units of knowledge in a domain" (Rittle-Johnson, Siegler & Alibali, 2001, pp. 346-347). Unlike conceptual understanding, conceptual misunderstanding involves conceptions that are "wrong and flawed" (Gurel, Eryılmaz & McDermott, 2015) and in conflict with scientific knowledge or claims. These conceptions may be termed alternate conceptions, misconceptions, "preconceptions, alternative frameworks, children's science, [or] naive conceptions" (Coştu, Ayas & Niaz, 2012, p. 49). Misunderstandings and misconceptions can be persistent (Sangam & Jesiek, 2012), interfere with learning (Ebenezer, Chacko, Kaya, Koya & Ebenezer, 2010), and resist change (Turgut, Gurbuz & Turgut, 2011).

Promoting conceptual understanding involves shifting misconceptions "toward more scientific ones" through a process of conceptual change (Coştu et al., 2012). Conceptual change was initially theorised by Posner, Strike, Hewson and Gertzog, (1982). Ebenezer et al. (2010) explained conceptual change as a process that involves learners first exploring their conceptions, becoming aware of those conceptions, sharing them "within a learning community", comparing them "with scientific models and explanations for plausibility" and subsequently "refining, reconstructing, reconciling or rejecting personal conceptions to align with the scientifically sound and agreed upon conception" (p. 2). Ultimately, the goal is to help students realise that "there are other competitive conceptions that may be more suitable for explaining a phenomenon" (Lin, Yen, Liang, Chiu & Guo, 2016, p. 2633).

There is no one approach or method to remediating "competitive conceptions", rather there are "a variety of instructional methods" or approaches and these may be more suited to one subject than another (Lin et al., 2016). Constructivist approaches to learning with their emphasis on actively building knowledge and meaning as well as sense making can help promote conceptual change. In terms of specific constructivist techniques and strategies, providing learners with an opportunity to explain can promote understanding. Williams, Lombrozo and Rehder (2010) found that engaging in explanation, even to oneself, can lead to conceptual change by "driving learners to discover underlying patterns." Williams et al. posited that "explaining exerts constraints on processing that drive people to interpret what they are learning in terms of underlying patterns and regularities." They add: "explanations cite generalizations that *subsume* what is being explained." Explaining helps learners develop an awareness of their prior knowledge by revising their beliefs after becoming aware of gaps in their understanding (Williams & Lombrozo, 2012). This awareness also develops by focusing attention instead of accepting "incomprehension", and engaging in a metacognitive process of monitoring their understanding (Denancé & Somat, 2015).

In addition to explaining the world, learners can enact in it. Enacting is more than simply learning by doing or hands-on learning. In a context of science, enacting involves acting out scenarios or testing hypotheses and predictions. Enacting can be relevant with *if-then* scenarios or *what-happens-if* scenarios. Hypothetical scenario enactments (McDonald, 2013) as a type of experiential learning provide learners the opportunity to carry out or perform simple experiments. For example, in a context of teaching students about electric circuits, students could be asked the following question: "Immediately after the switch is opened, what happens to the resistance of the bulb?" (Engelhardt, 1997, p. 117). Students can then be provided with equipment that allows them to enact or perform a small experiment to see what happens after they open the switch. Ideally, the enacting should take place in contexts that replicate the real world. Like learning by explaining, learning by enacting engages learners in verifying their assumptions and activating prior knowledge in order to progressively scaffold to higher levels of understanding.

Learning by explaining and enacting can be scaffolded by *predict-observe-explain* (POE) strategies. POE strategies involve learner-centred teaching that emphasises socially-constructed knowledge (Kibirige, Osodo & Tlala, 2014, p. 304). The strategies help students put forth and test hypotheses (Kibirige et al., 2014). There are two psychological factors in POE. The first is a memory factor which means that learners remember things better when they have actively engaged in thinking about something rather than simply receiving knowledge passively (Dalziel, 2010). The second factor relates to the student's confidence in the prediction and involves reflection on one's thought processes or metacognition (Dalziel, 2010). Karamustafaoğlu and Mamlok-Naaman (2015) explained that POE strategies typically include three tasks involving *if-then* logic. In the first task, students are given a physical situation for which they should predict "the result of a specific change to the physical situation" and explain their prediction (p. 924). In task two, they describe their observation. In task three, they explain the difference between their initial prediction and the final result. POE strategies can help students engage in inquiry and critical thinking (Karamustafaoğlu & Mamlok-Naaman, 2015), develop their independence (Chen, Pan, Sung & Chang, 2013), and motivation and make learning more interesting and permanent (Karamustafaoğlu & Mamlok-Naaman, 2015). They can help "students to support their predictions through benefiting their existing knowledge and experiences of similar events that they encountered in their daily life" (Ayvaci, 2013, p. 549).

Using POE strategies with multimedia and virtual interactive simulations

A particular challenge with using POE-type strategies in the classroom is providing students with opportunities to observe scientific phenomenon in a way that is real, authentic and, most importantly, safe (Kearney, 2003). To overcome this challenge, Hussain, Haron, Salim, Rosmah and Hussain (2013) used virtual simulations with POE strategies in an undergraduate, basic electric circuits course. The authors explained that the topic is abstract therefore simulations can help students visualise these abstractions. In general, computer simulations are a tool that can be used to change students' misconceptions about electricity (Ersoy & Dilber, 2014; Hussain et al., 2013). Virtual computer simulations are useful for learners to visualise aspects of science and observe the results of interactions (Hussain et al., 2013). Kearney and Wright (2002) used a computer program to help science teachers build photographic, sound or video-based (digital) demonstrations. Kearney (2003) focused on the use of POE tasks in a technology-based multimedia environment with peer conversation to probe students' understanding in science. He used digital video clips to replace real-life experiments in a physics lesson on force. Kearney aimed to provide students with opportunities to observe "difficult, expensive, time consuming or dangerous demonstrations of real, observable events" (p. 427).

Kearney, Treagust, Yeo and Zadnik (2001) found three affordances of multimedia-based POE tasks. First, students can control the pacing of POE tasks and the presentation of video-based demonstrations. Next, they can make detailed observations of physical phenomena using digital, video-based demonstrations in the observation phase. Finally, students must describe the virtual, real-life physical setting in the video-clips. The advantages of using computer-based video clips are that students can control and observe experiments as many times as they want. In addition, the clips provide content for the "reflective discussions" that take place during the observation step of the model (Kearney, 2003). Banky and Wong (2007) described advantages of use of simulation software in terms of the capacity to let users observe outcomes without harm and without the inconvenience of equipment failure.

Kearney (2003) summarised the advantages of assigning POE tasks for completion in a computer-based environment. These include opportunities for small-group work, computer scaffolding, student pacing and autonomy, and opportunities for discussion and reflection. In addition, Kearney noted that computer-based demonstrations "can reveal interesting science phenomena that… go beyond our temporal, perceptual or experiential limits" (p. 427). Similarly, Ajredini, Izairi and Zajkov (2013) found that, compared to real experiments related to electrical charging, virtual experiments using computer simulations resulted in significantly higher "quality knowledge and skills" (p. 59). Wibowo et al. (2016) studied the effects of computer simulations to teach about dry-cell batteries and found those students who used the simulation "exhibited significantly higher scores" (p. 9).

PhET simulations for learning by enacting

One type of computer simulation is the *Physics Education Technology Project* (PhET) (Perkins et al., 2006). These are free simulations accessible from the project's website (http://phet.colorado.edu) that can be downloaded for offline use. The PhET project is designed to engage learners in "animated, interactive, and game-like environments" that "emphasize the connections between real-life phenomena and the underlying science" (Perkins et al., 2006, p. 18). Like simulations in general, the PhET simulations aim to show what is "not ordinarily visible to the eye" (Perkins et al., p. 18). Ganasen and Shamuganathan (2017) found that effective use of computer simulations depended on the learning environment and on "teachers' ability to encourage interaction among students" (p. 176) using a constructivist approach to learning.

The present study: Learning by explaining and enacting

POE-type strategies can be effective for many levels of students including university (e.g. Hilario, 2015), secondary school (e.g., Berek, Sutopo & Munzil, 2016), elementary (Acar Şeşen & Mutlu, 2016) and primary school (Demircioğlu, 2017). Dewantoro, Subandi and Fajaroh (2018) found that POE strategies increased vocational students' understanding in mass balance. However, there are fewer examples of use of POE-type strategies for learners in vocational, apprenticeship, trade or technical programs. What is needed in order to use POE-type strategies with students in vocational, apprenticeship, trade or technical programs is an emphasis on both activity and theory (Ahmad, Nordin, Ali & Nabil, 2015). This is because these learners require learning approaches that emphasise activities and tasks along with theory (Ahmad et al., 2015).

Vocational education and training (VET) represents a relevant context to investigate strategies that promote conceptual understanding. VET offers "opportunities for youths to acquire skills that are valuable in the labor market" and combines general with "occupational knowledge" (Eichhorst, 2015, p. 2). Hoeckel (2007) argued that there has been a lack of attention to VET pedagogy. Similarly, Lucas (2014) posited that VET pedagogy is "under-researched and under-theorised" (p. 2). Furthermore, there is a lack of literature regarding "the impact of vocational pedagogy on learners" (Cedefop, 2015, p. 12). There is a need to understand vocational pedagogies to support policy and to help "develop models and tools which can help VET teachers and trainers more effectively match teaching and learning methods to the needs of their students and their contexts" (Cedefop, 2015, p. 1). Similarly, the emphasis on reform and inclusiveness in VET calls for "new pedagogical approaches and learning materials" (Marope, Chakroun & Holmes, 2015, p. 82). Researchers also need "ways to test out new resources and pedagogies in a culture of active experimentation" (Hillier, 2009, p. 30).

In this study, we designed and tested a new strategy that emphasises learning by explaining and enacting. The strategy is called *predict-explain-enact-observe* (PEEO). We relied on a PEEO strategy to address vocational students' misconceptions about electric circuits. The topic of electricity is abstract and intangible thus, many students form incorrect understandings and fail to grasp the related concepts (Jaakkola, Nurmi & Veermans, 2011). In addition, students sometimes rely on intuitive conceptions to understand electricity and electric circuits (Chen et al., 2013; Kollöffel & Jong, 2013). The study's research questions were as follows:

1. What is the effect of explaining on learners' (N=40) understanding?
2. What is the effect on learners' misconceptions of traditional electric circuits board (n=20) versus virtual interactive simulation (n=20) for enacting?

The results of the study will be particularly relevant to those designing or delivering vocational, apprenticeship, trade or technical programs. However, they are likely to be relevant in any context where there needs to be an emphasis on promoting conceptual understanding and remediating misconceptions.

Conceptual framework: From DOE to PEEO

Originally, there were the *demonstrate-observe-explain* (DOE) strategies (Champagne, Klopfer & Anderson, 1980). Champagne et al. (1980) used this strategy to assess students' understanding of force in first-year physics. The advantages of DOE strategies include a reduction in the quantity of verbal description and a reliance on open-ended questions that provide data to make inferences about students' conceptualisations (Champagne et al., 1980). White and Gunstone (1981) redesigned the DOE strategies and developed the first POE model in elementary-school science. According to their model, students must predict the outcome, justify their prediction, describe their observation and then reconcile contradictions between what they predicted and what they observed.

Savander-Ranne and Kolari (2003) developed *predict-discuss-explain-observe-discuss-explain* (PDEODE) strategies to investigate students' understanding of science. These strategies involve motivating students' prior knowledge and solving contradictions between their beliefs and observations. Sani (2012) developed *predict-observe-explain-write* (POEW) strategies that combine POE and *think-talk-write* (TTW) to improve students' higher-order thinking. Hilario (2015) developed the *predict-observe-explain-explore* (POEE) approach designed to stimulate students' interest and curiosity between their knowledge of chemistry and their life. Bajar-Sales, Avilla and Camacho (2015) developed *prediction-*

explanation-observation-explanation (PEOE) strategies for constructing and negotiating ideas after student predictions. Figure 1 summarises these strategies.

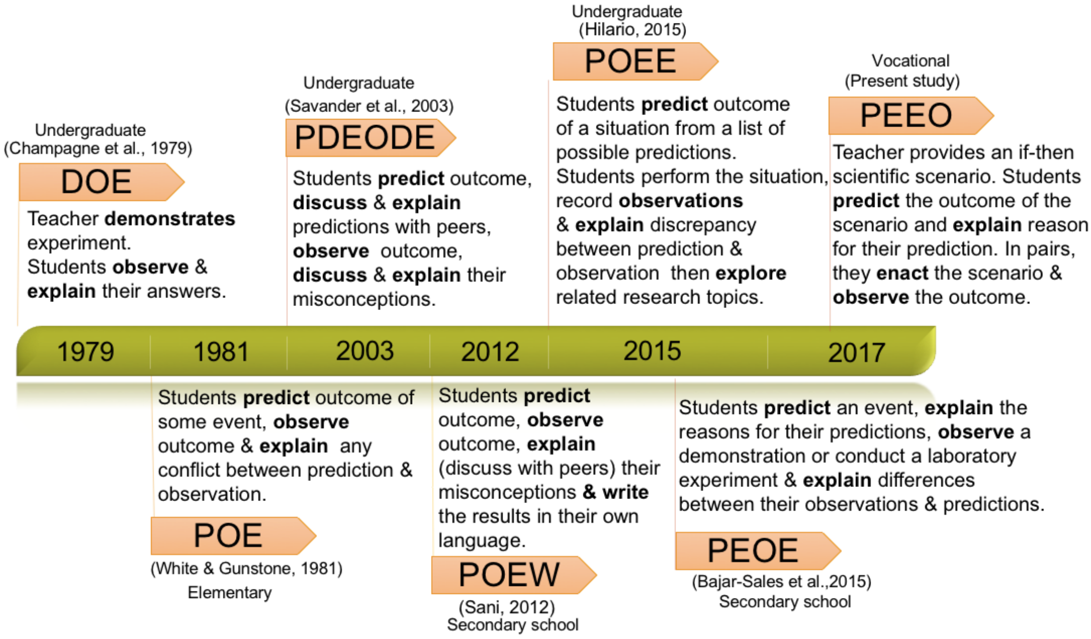


Figure 1: Chronological overview of some POE-type strategies

Methods

Context: Vocational education in Thailand

This study relied on one case of vocational education at the secondary school level in Thailand. Students can follow a three-year program and receive upon completion a certificate in vocational education. This three-year formal program combines "theoretical and practical subjects" with one semester in the workplace (Ratchusanti, 2009, p. 4). Students have the option of completing the Certificate in Dual Vocational Education, also a three-year program. The difference is that, in this program, students learn in school and in a company workplace where they receive practical training as well as an allowance (Ratchusanti, 2009, p. 4). Programs are offered in "areas of trade & industry, business, agriculture, home economics, arts and crafts, fisheries, textile, garments, jewelry" (Ratchusanti, 2009, p. 9). Those who choose to enter the vocational stream complete three years of coursework, after which they obtain a diploma and they may continue to higher VET at tertiary institutions (Chookaew, Wongwatkit & Howimanporn, 2017, p. 100). In total, 415 public colleges and 427 private vocational schools/colleges operate in the country with student enrolments of 0.7 million and 0.4 million respectively (Prontadavit & Hanvatananukul, 2017, p. 191).

The research design

The study tested the effect of a PEEO strategy on learners' (N=40) understanding by requiring them to give explanations for their predictions. It was beyond the scope of the study to use a control and experimental group to test the effect of the PEEO strategy. The teaching context required use of the strategy for all students. The study also tested the effect on learners' misconceptions of using a PEEO strategy that required them to enact their prediction using an electric circuits board (n=20) versus PhET virtual interactive simulation (n=20). For this stage of the study, we relied on two groups: the virtual simulation (VS) group and circuits board (CB) group. Both groups were selected randomly. Figure 2 provides an overview of the research design. A two-tiered pre-test was administered before the intervention and a post-test was administered after the intervention. The instrument for testing was the *Determining and Interpreting Resistive Electric Circuit Concepts Test* (DIRECT) (Engelhardt, 1997) along with a second tier of questions that prompted students to explain their predictions before they enacted the scenario.

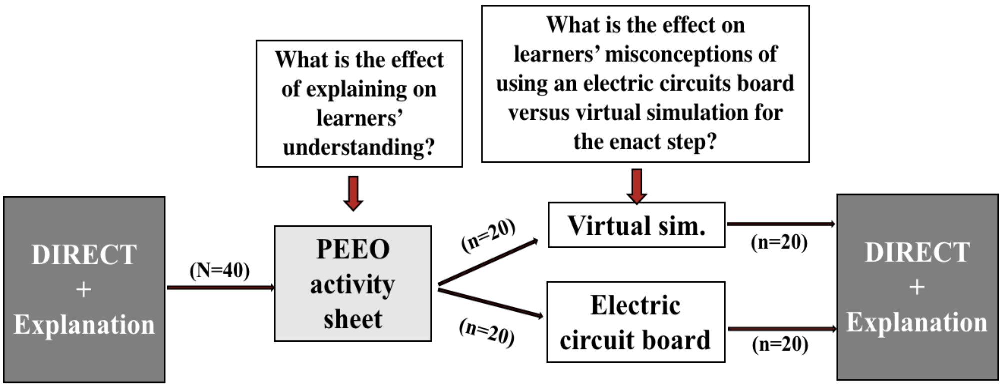


Figure 2: The research design

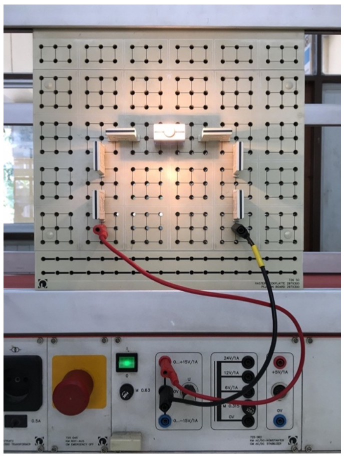


Figure 3: The electric circuits board

PhET, circuit construction kit simulation

Participants in the VS group relied on a specific PhET sim called the *Circuit Construction Kit* (CCK) simulation. The CCK offers "powerful tools for understanding current and investigating cause-and-effect relationships between voltage, current, resistance, and power" (Perkins et al., 2006, p. 22). The kit "provides an open workspace where students can manipulate resistors, light bulbs, wires, and batteries" (Finkelstein et al., 2005, p. 2). Students can use the workspace to build circuits and measure current and voltage "using virtual ammeters and a voltmeter" (Keller, Finkelstein, Perkins & Pollock, 2007, p. 121).

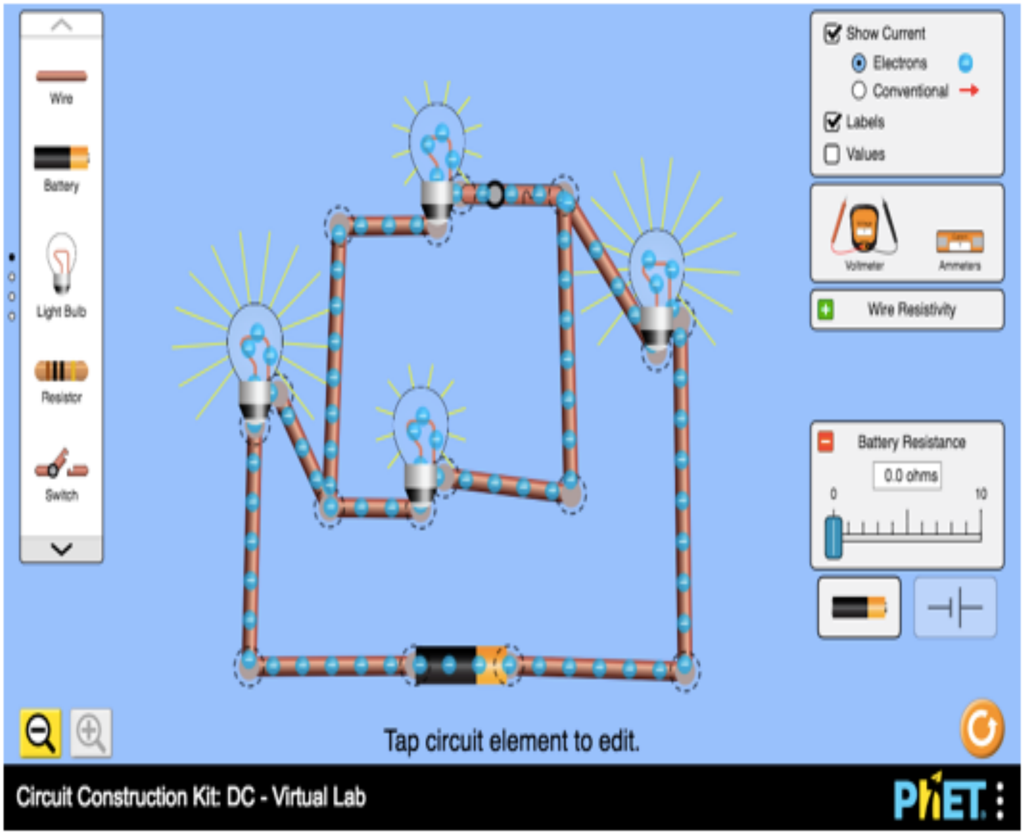


Figure 4: Screenshot of the PhET Circuit Construction Kit: Direct current (DC)

Participants

All students were enrolled in a vocational certificate (first year) in a technical college in an urban area of Thailand. The students in both groups were aged 14-16 years and studying to be electricians. The CB group consisted of 20 students. The VS group also consisted of 20 students. All participating students were male because there were no female students enrolled in the program when the study was conducted.

Procedures

The intervention spanned four weeks in July 2017. The same teacher (principal investigator) taught both groups to minimise biases. Both groups attended class for two hours per week. Both groups used a PEEO activities' sheet designed for the study. The sheet featured 12 scenarios related to the types of misconceptions (e.g., unipolar, clashing current, shared current, etc.). Students worked on three scenarios per week for four weeks, two hours each time. The activity sheet for all scenarios relied on four boxes; three for each of *predict, explain, observe* and one for *enact*. Students recorded each step on the activity sheet. Figure 5 summarises the PEEO strategy. Figure 6 shows the activity sheet.

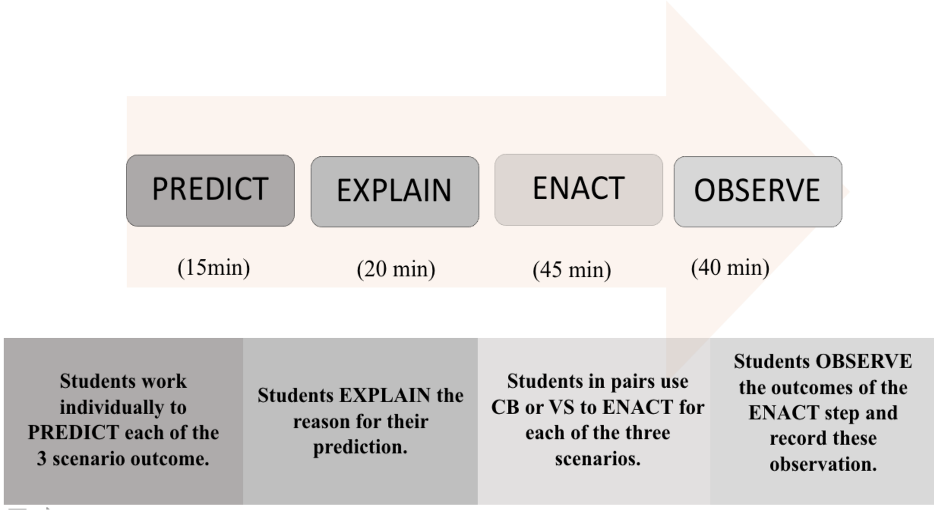


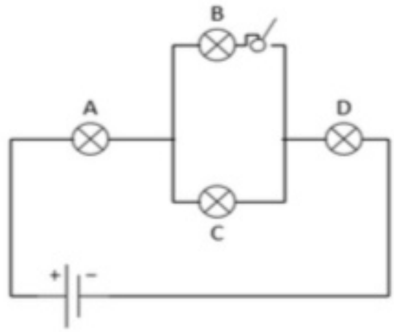
Figure 5: PEEO

Instruments

The DIRECT was administered in Thai to both groups before and after the intervention. The test provides an instrument to evaluate students' "conceptual difficulties" and reasonings that "differ from the accepted explanations" (Engelhardt & Beichner*,* 2004, p. 98). In this study, we used the test to measure the overall change in students' misconceptions before and after learning with the PEEO strategy. The DIRECT is a concept inventory made of "multiple-choice questions in a particular conceptual domain, with common misconceptions presented as 'distracters'" (Sangam & Jesiek, 2012). The test's reliability and validity have been well established (Sangam & Jesiek, 2012). The test consists of 29 questions including four concepts about electric circuits, namely physical aspects of DC electric circuits, energy, current, and potential difference (voltage). The categorisation of each question follows the type of misconceptions in electric circuits (see Table 1). Engelhardt (1997) explained the advantages of the DIRECT compared to other instruments in that it "covers more topics than the other tests. It is not associated with any particular curriculum … [which] makes the results more valid and generalizable" (p. 66).

Scenario 3

Shared current



If the switch is closed, then which bulb will light and which one is the brightest?

Procedure

1. Predict the outcome of the scenario.

2. Explain your prediction.

3. Pair with a friend. Complete the experiment as noted in Enact box below.

4. Observe the results. Record your observation.

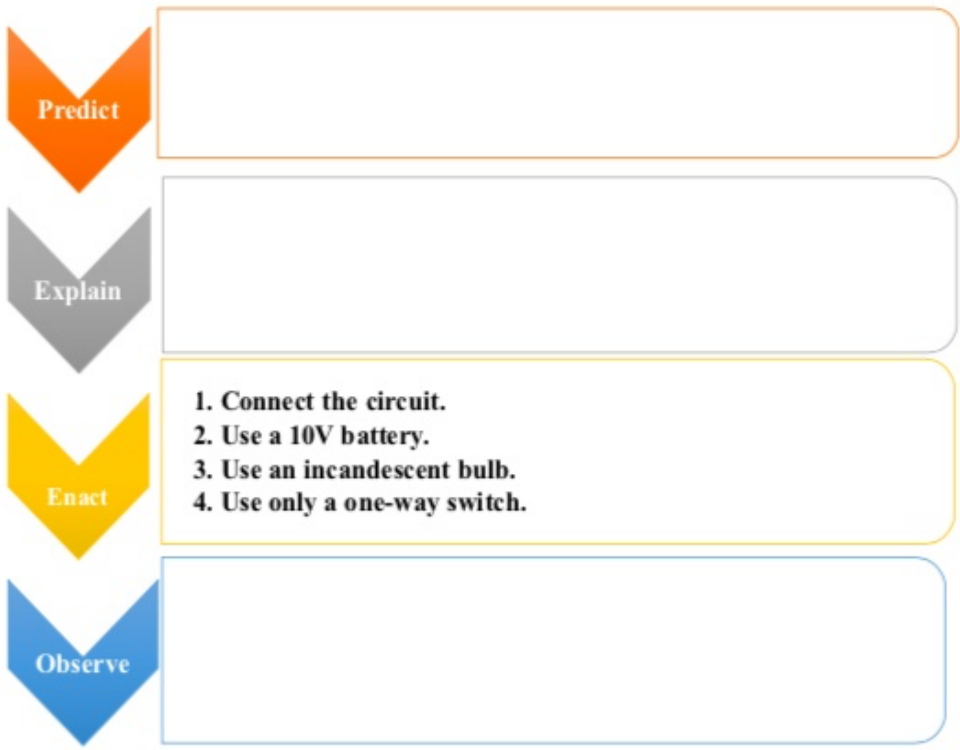


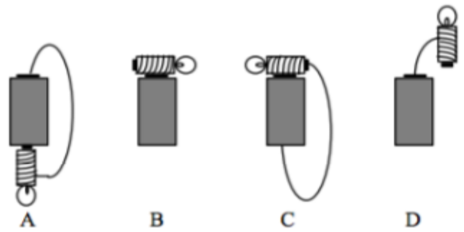
Figure 6: An example of a scenario on the activity sheet

Table 1: The contents of DIRECT (Engelhardt & Beichner, 2004, p. 100)

Contents	Objectives	Sub-contents example	Items
Physical aspects of DC electric circuits	1-5	Identify and explain a short circuit, complete circuits, resistance.	4, 5, 9, 10, 13, 14, 18, 19, 22, 23, 27
	1-3		27
Energy	6-7	Apply the concept of power to a variety of circuits and understanding of energy.	2, 3, 12, 21
Current	8-9	Understand and apply conservation of current and current flow.	1, 8, 11, 17, 20
Potential diff. (voltage)	10-11	Apply the concept of potential difference to a variety of circuits.	7, 16, 25
			6, 15, 24, 28, 29
Current and potential diff.	8-11	-	26

To focus specifically on learning by explaining, we added a second tier of questions to the test. These questions invited students to give explanations for their predictions (e.g., Why will the bulb light?). Two-tier tests have been used to identify students' misconceptions (Kanli, 2015) and investigate understanding (Yang, Chen & Hwang, 2015). Figure 7 provides an example of a test item with the second tier.

Which circuit(s) will light the bulb?
(A) A
(B) C
(C) D
(D) A and C
(E) B and D



Your explanation: Why will the bulb light?
....
....
....

Figure 7: Example of one DIRECT item with explanation
(Engelhardt & Beichner, 2004, p. 31)

Data analysis

The Wilcoxon signed-rank test was used for the correlation measurement in the comparison of the pre-test and post-test scores between groups. The Mann-Whitney U test was used to test the significance between the result of the pre-test and post-test of both groups (N=40).

Students' explanations were grouped according to one of the following four categories (adapted from Çalik, Ayas & Coll, 2009; Haidar, 1997):

1. Complete understanding (CU): Student understands all concepts;
2. Partial understanding (PU): Student shows a partial understanding of at least one of the concepts;
3. Misunderstanding (MU): Student provides incorrect explanation;
4. No understanding (NU): Student does not provide an explanation (no response).

Results

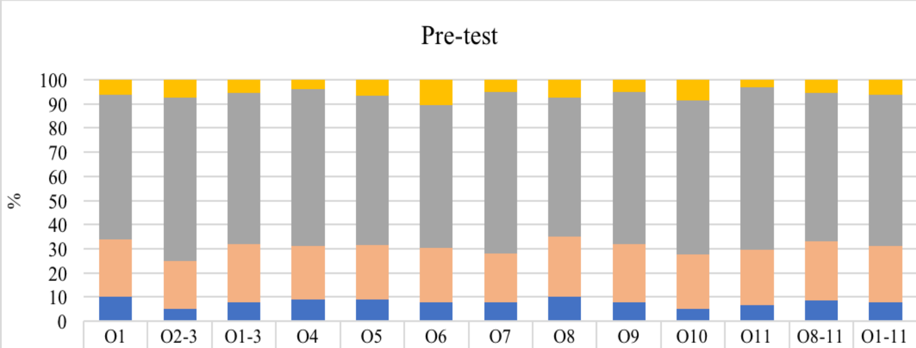
Research question 1

What is the effect of explaining on learners' (N=40) understanding?

Figure 8 shows results of students' (N=40) explanations of their predictions. The pre-test results averaged over all objectives showed 8% CU, 23% PU, 63% MU, and 6% NU. Pre-test results revealed that the highest percentage of CU (10%) was in objectives 1 and 8. The lowest (5%) was in objectives 2-3 and 10. The highest percentage of PU was with objective 8 (25%) while the lowest was with objectives 2-3 and 7 (20%). The highest percentage of NU was in objective 6 (10.5%) while the lowest was objective 11 (3%).

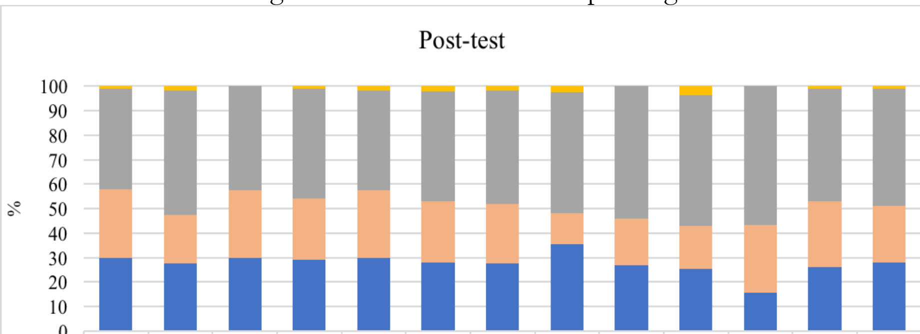
Figure 9 shows post-test results. The highest percentage of CU (35.5%) was in objective 8 and the lowest percentage (15.5%) in objective 11. For PU, the highest percentage was with objectives 1 and 11 (28%) while the lowest was in objective 8 (12.5%). The highest percentage of NU was objective 10 (3.5%) while the lowest was with objectives 1-3, 9 and 11 (0%). Objective 8 (current) showed the highest increase of CU (from 10% to 35.5%) while objective 11 (potential difference, voltage) showed the lowest increase (from 6.5% to 15.5%).

Figures 10 a-b compare between pre-test and post-test. The figures show totals for all items/objectives with CU, PU as well as MU, NU. The results show that the percentage of CU increased overall from 8% to 28%, the percentage of MU remained stable at 23%, the percentage of PU decreased from 63% to 48% and NU decreased from 6% to 1%.



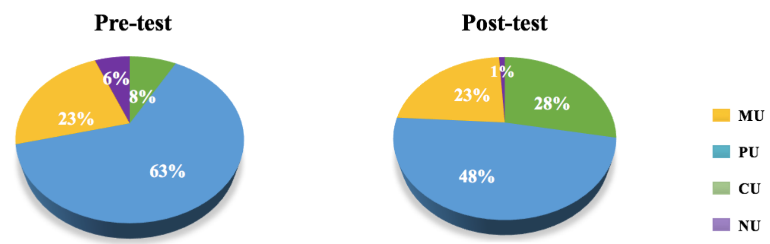
	O1	O2-3	O1-3	O4	O5	O6	O7	O8	O9	O10	O11	O8-11	O1-11
NU	6	7.5	5.5	4	6.5	10.5	5	7.5	5	8.5	3	5.5	6
MU	60	67.5	62.5	65	62	59	67	57.5	63	64	67.5	61.5	63
PU	24	20	24	22	22.5	22.5	20	25	24	22.5	23	24.5	23
CU	10	5	8	9	9	8	8	10	8	5	6.5	8.5	8

Figure 8: Pre-test results of explaining



	O1	O2-3	O1-3	O4	O5	O6	O7	O8	O9	O10	O11	O8-11	O1-11
NU	1	1.5	0	1	1.5	2	2.5	2.5	0	3.5	0	1	1
MU	41	51	42.5	45	41	45	46.5	49.5	54	53.5	56.5	46	48
PU	28	20	27.5	25	27.5	25	24.5	12.5	19	17.5	28	27	23
CU	30	27.5	30	29	30	28	27.5	35.5	27	25.5	15.5	26	28

Figure 9: Post-test results of explaining



a) Pre-test

b) Post-test

Figure 10 a-b: Pre-test and post-test comparisons for explaining

Table 2 presents the results of a paired sample t-test showing a significant improvement in students' understanding between the pre-test and post-test ($p < .05$)

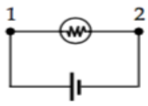
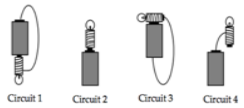
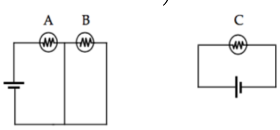
Table 2: Paired sample t-test of significance for CU

	N	Mean	SD	t	*p*
Pre-test	40	7.69	5.093	-9.273	.001*
Post-test	40	31.21	16.347		

*$p < .05$

Table 3 shows examples of CU, PU and MU using Engelhardt's (1997, pp. 214-215) questions and answers.

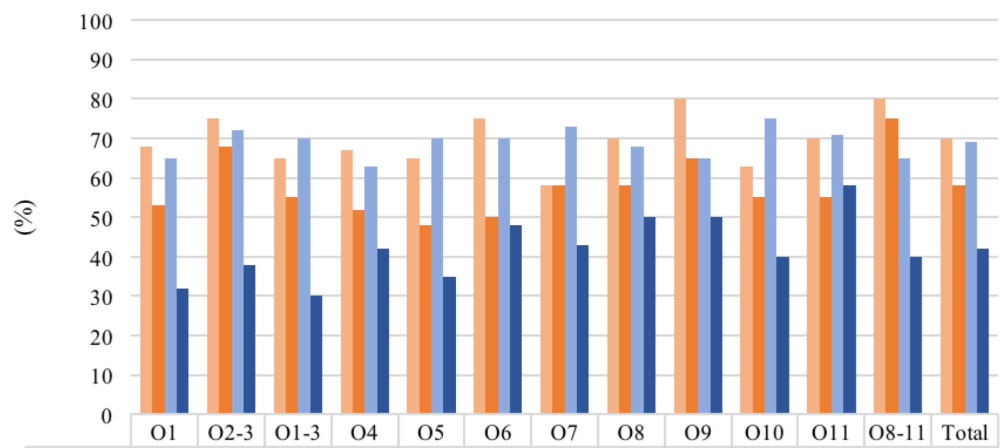
Table 3: Examples of CU, PU and MU

#	Question	Question	CU	PU	MU
8	Compare the current at point 1 with the current at point 2. Which point has the LARGER current? (Answer: Neither. They are the same) 	Why is the current larger at that point?	They are the same because the current travels in one direction around the circuit.	They are the same because the current travels in two directions around the circuit.	Point 1 is the largest because it is nearer the battery than point 2.
9	Which circuit or circuits will light the bulb? (Answer: Circuits 1 & 3) 	Why will the bulb light?	Because there is a wire connecting the negative pole of the battery to the positive pole of the bulb to complete the circuit.	Because there is a wire connecting the battery with the light bulb.	Because the light bulb is connected to the battery.
10	Compare the brightness of bulbs A, B and C in these circuits. Which bulb or bulbs are the BRIGHTEST? (Answer: A = C) 	Why is that bulb the brightest?	Bulbs A & C are connected as a series circuit. Therefore, A and C will be brightest.	Bulb A or (C) is connected as a series circuit.	The bulb B is connected as a series circuit.

Research question 2

What is the effect on learners' misconceptions of using a PEEO strategy with electric circuits board (n=20) versus a virtual simulation (n=20) for enacting?

Figure 11 compares the pre-test and post-test results between the CB and VS groups organised according to the objectives of the DIRECT. Pre-test results for the CB group revealed that the highest percentage of misconceptions (80%) was in objectives 9 and 8-11, and the lowest (58%) in objective 7. Results for the VS group revealed that the highest percentage of misconceptions (75%) was in objective 10, and the lowest (63%) in objective 4. Post-test results show that, for both groups, there was a decrease in the percentage of misconceptions. The highest gains for the CB group were in objective 5 (65% pre-test, 48% post-test). The highest gains for the VS group were in objectives 1-3 (70% pre-test, 30% post-test). The lowest gains for the VS group were in objective 9 (65% pre-test, 50% post-test). The only exception is for objective 7 for the CB group which remained unchanged from pre- to post-test. Misconceptions decreased from 70% to 58% for the CB group and from 69% to 42% for the VS group.



	O1	O2-3	O1-3	O4	O5	O6	O7	O8	O9	O10	O11	O8-11	Total
Pre-CB	68	75	65	67	65	75	58	70	80	63	70	80	70
Post-CB	53	68	55	52	48	50	58	58	65	55	55	75	58
Pre-VS	65	72	70	63	70	70	73	68	65	75	71	65	69
Post-VS	32	38	30	42	35	48	43	50	50	40	58	40	42

Figure 11: Percentage of pre-post misconceptions for both groups organised by objective (O)

Table 4 shows the pre- and post-test means for both groups. The pre-test mean for the CB group was 69.70% (SD =3.593) and for the VS group, 69.40% (SD=5.986). Post-test results show that misconceptions decreased from a mean of 69.70% to 57.80% for the CB group, and from 69.40% to 41.50% for the VS group.

Table 4: Pre- post-test scores for both groups

Group		Mean	Median	Mode	SD	Max	Min
CB	Pre-	69.70	69.5	72	3.593	76	62
	Post-	57.80	59	59	6.732	70	45
VS	Pre-	69.40	69	69	5.986	83	59
	Post-	41.50	42	45	5.463	52	31

Table 5 presents results of the Mann-Whitney U test. There was not a significant difference between the pre-test scores of either group (U= 186.000, $p > .05$). However, post-test scores showed significant improvements for the VS group compared to the CB group (U= 16.000, $p < .05$).

Table 5: Results of Mann-Whitney U test of the pre- and post-test of both groups

Groups	N	Mean rank	Sum of ranks	U	z	*p*
CB (pre)	20	19.80	396.00	186.000	- .387	.718
VS (pre)	20	21.20	424.00			
CB (post)	20	29.70	594.00	16.000	-5.010	.001*
VS (post)	20	11.30	226.00			

* $p < .05$

Table 6 shows the results of the Wilcoxon signed rank test. There was a statistically significant difference between post-test and pre-test scores of the CB group (z = -3.887, $p < .05$) and the VS group (z = -3.923, $p < .05$). The results show that the decrease in students' misconceptions was significantly greater for the VS group (mean rank 10.5 vs. mean rank 11.00).

Table 6: Results of Wilcoxon signed-rank test for overall misconceptions for both groups

		n	Mean rank	Sum of ranks	z	*p*
CB Post-test – pre-test	Negative ranking	19	11.00	209.00	-3.887*	.001
	Positive ranking	1	1.00	1.00		
	Ties	0				
	Total	20				
VS Post-test – pre-test	Negative ranking	20	10.50	210.00	-3.923*	.000
	Positive ranking	0	.00	.00		
	Ties	0				
	Total	20				

* z = based on negative ranks, $p < .05$

Discussion

The first research question asked what is the effect of explaining on learners' (N=40) understanding? Results showed a significant improvement in students' understanding between the pre- and post-test. This result suggests that learning activities requiring students to explain their predictions about scientific phenomena can increase understanding. These results confirm those of Samsudin, Suhandi, Rusdiana, Kaniawati and Coştu (2016) who used *predict-discuss-explain-observe-discuss-explore-explain* (PDEODEE) tasks to promote conceptual change of pre-service teachers (N=7) in electric field concepts. The authors measured conceptual change using the *Field Conceptual Change Inventory*. Their results showed that PDEODEE tasks changed pre-service physics teachers' misconceptions and enhanced their conceptual understanding in the electric field. However, some misconceptions remained unchanged as was the case in this study. Kapartzianis and Kriek (2014) used conceptual change model-based activities to investigate vocational students' (N=15) understanding of electric circuits. They used the DIRECT along with field notes and interviews to analyse conceptual understanding. Their results revealed a significant improvement from pre- to post-test. The highest percentage of change from (pre) to (post) was 54% in objective 9. The percentages of change were lower in this study. For example, for objective 9, the CU increased from 8% to 27%.

After using PEEO strategies, students in this study improved the percentage of CU from 8% to 28%. Similarly, Coştu et al. (2012) investigated the effectiveness of PDEODE activities to enhance undergraduate Turkish students' (N=51) understanding of condensation. They assessed students' conceptual change by concept test and interviews. Results showed a decrease in students' "alternative conceptions" (p. 63). The highest percentage of conceptual change was +29% from pre- to post-test. For their 'sound understanding' category, students' responses increased from 4% to 83%. The significant gains in this study also confirm results of Phanphech and Tanitteerapan's (2017) study related to learning about electric circuits. Participants in that study had already graduated from secondary school and were participating in higher vocational education and training. The control group (n=20) learned with lecture and laboratory experiences. The experimental group (n=20) used *predict-do-observe-explain* (PDOE) strategies. The authors found that there was a significant difference favouring the experimental group ($p < .05$) using the PDOE strategies. Results were reported for the post-test of current only because that was the area where students had the most misconceptions. Students' misconceptions about current decreased by approximately 45% for the experimental group. In this study, for objectives 8-9 about current, students' misconceptions decreased from 10% to 35% (O8) and from 8% to 27% (O9). Results from this study are only for complete understanding (CU), whereas in Phanphech and Tanitteerapan's study, results were for misconceptions overall.

The second research question asked what is the effect on learners' misconceptions of using an electric circuits board (n=20) compared with virtual interactive simulation (n=20) for enacting? Results revealed a significant improvement from pre- to post-test for both groups. This result suggests that, like explaining, enacting increased students' understanding. However, the VS group had significantly fewer post-treatment misconceptions than the CB group. The gains within the CB group suggest that requiring students to enact or perform the if-then scenarios improved conceptual understanding by significantly reducing the number of misconceptions. The significant difference between groups suggests that the virtual simulations were more effective than the electric circuits board.

The significant gains by the VS group in this study confirm results of other studies that used computer simulations. For example, Kolçak, Moğol and Ünsal (2014) studied Grade 10 physics students (N=48). They found that the experimental group's use of computer simulations was more effective than the conventional method for reducing misconceptions. Similarly, Taşlidere's (2013) results with pre-service science teachers (N=139) revealed that after using PhET, the percentage of misconceptions about direct current electric circuits decreased from 10.8% to 6.8%. Farrokhnia and Esmailpour (2010) investigated undergraduate students' understanding of direct current electric circuits (N=100) with the DIRECT as pre- and post-test. They compared physical (n=30), PhET virtual simulations (n=35) and a combination of virtual and physical (n=35) methods to change students' conceptual understanding and skills. Their results were similar to those of the present study, with no statistically significant differences ($p>.05$) in pre-test scores but significant differences ($p<.05$) in post-test scores.

Sangam and Jesiek (2012) studied "conceptual understanding of resistive electric circuits" with first-year engineering students (N=150). The authors relied on the DIRECT before and after an instructional module on circuits. The module included "web-based simulations, contextual problems, design problems, qualitative problems, and hands-on experiential learning with breadboard and LEDs." Results showed "predominantly positive changes," however "a large majority of the students had persistent difficulties… With one week of instruction, their performance on the concept inventory only increased by 7%." Like Sangam and Jesiek's participants, students in this study also had persistent difficulties.

Findings of this study are unlike those of Başer and Durmuş (2010). Başer and Durmuş studied pre-service elementary school teachers' (N=80) understanding about direct current electric circuits. They compared the effectiveness of a virtual learning environment (VLE) and a real laboratory environment (RLE) to promote conceptual understanding. They used the DIRECT to investigate pre-service teachers' conceptual understanding. Their results showed no significant difference between the VLE and RLE groups ($p > .05$).

Conclusions

In this study, to investigate conceptual understanding, we focused on the domain of physics and learning about electrical circuits. We investigated this phenomenon with secondary school students (N=40) learning in vocational school in Thailand. The four-week intervention involved implementing strategies of explaining and enacting. Specifically, the 40 students were given practice in explaining their prediction, then enacting an if-then scenario and observing the results. During each two-hour session, students used a PEEO activity sheet with three scenarios per week related to types of misconceptions. In addition, the intervention investigated the effectiveness of using virtual simulations (n=20) versus traditional electric circuits board (n=20) for enacting (performing) the scenarios. To measure conceptual understanding, we relied on a reliable and validated concept inventory called the *Determining and Interpreting Resistive Electric Circuit*

Concepts Test (DIRECT). We added a second tier to the test that required students to engage in a metacognitive process of explaining. We administered the DIRECT before and after the intervention. To measure conceptual understanding, we looked at the reduction in the percentage of misconceptions overall. In addition, we categorised students' explanations into four categories of complete, partial, misunderstanding, or no understanding.

The treatments (*predict-explain-enact-observe* strategies + virtual simulation) did result in significant gains in understanding. However, the misunderstandings and misconceptions remained dominant compared to PU and CU combined. Understanding remained low (CU 30%). In this regard, this study's results confirm the depiction of misconceptions as 'persistent difficulties' (Engelhardt, 1997). A longer intervention period might have resulted in higher CU. It was beyond the scope of this study to test that hypothesis. Another factor that could have affected the results is the DIRECT. Although the test is considered a valid and reliable instrument, it may not have measured all the gains that students made in their understanding. It was beyond the scope of this study to employ a second instrument or to conduct individual interviews and observations.

This study was limited to a PEEO strategy with explanation of the prediction and enacting the if-then scenario. We do not know if an additional step in the strategy such as PEEOE with final explanation of the observation would have resulted in higher levels of understanding. Others have tried strategies beyond the PEEO type. For example, the activity sheet in this study might be replaced by computer-based narrative games (Pilegard & Mayer, 2016) or analogies (Orgill & Sutherland, 2008). The results do suggest that adding an additional strategy improves results. For example, using the virtual simulation for enacting the scenario was more effective than using PEEO on its own. Results may be context-specific, meaning that a strategy that improves understanding in one context may not do so in another, which might explain the difference in results between Başer and Durmuş' (2010) study versus this study. In terms of implications for research, it may be of value to determine which combinations of strategies and how many strategies might be implemented to improve understanding beyond the levels evidenced in this study. In terms of implications for practice, interventions such as those reported on in this study may benefit from student feedback on and evaluation of use of PEEO strategies. In this study, such feedback may have provided insights into why a high proportion of students achieved less than complete understanding.

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