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Impact of PhET Interactive Simulation in a Hybrid Physics Course: The Case of Repeating Students

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Abstract

In the evolving digital education landscape, distance learning and information technologies have significantly reshaped pedagogical practices, introducing opportunities and challenges. This study explores the adaptation of Interactive Lecture Demonstration (ILD), traditionally an in-person educational approach that enhances student engagement and understanding, for online delivery within a hybrid physics course. Specifically, it examines the implementation of a modified online ILD methodology incorporated with PhET simulations in a Chilean private university's first-year physics course, focusing on repeating students. A cross-sectional quantitative analysis was conducted with 33 out of 50 enrolled students participating. The innovative teaching strategy involved a dual-modality approach: demonstrations were introduced during in-person lectures where students made initial predictions, and online collaborative workshops using PhET simulations allowed students to test these predictions. The effectiveness of this method was assessed at the semester's end through a validated conceptual inventory test (DIRECT), aiming to gauge the students' understanding of electrical circuits. Findings indicate that while students showed an initial grasp of basic principles, they faced challenges in applying this knowledge to complex circuit configurations and differentiating between potential differences and current flows, suggesting a gap in deep conceptual understanding. This underscores the importance of targeted instructional interventions and integrating diverse educational tools to improve comprehension and application in realistic scenarios.

Keywords: circuits, potential differences, current, Phet simulations, physics course, engineering students, educational innovation, higher education

Introduction

In the wake of the COVID-19 pandemic and the subsequent shift to Preventive and Mandatory Social Isolation measures, educators and students alike have been prompted to reevaluate traditional teaching structures [1], [2]. This global crisis has accelerated the adoption of hybrid teaching modalities, necessitating innovative approaches to ensure effective learning outcomes [3] – [5].

Among these approaches, the Interactive Lecture Demonstration (ILD) methodology, pioneered by [6] Sokoloff and Thornton in 1997, has emerged as a prominent strategy in science education. In this dynamic, each student anticipates a physical phenomenon by viewing an experiment conducted by the teacher. Subsequently, discussion is encouraged, and conclusions are reached as a group, thus enriching the collective understanding of the topic. Active learning occurs when students spark their curiosity and work on challenges they face while solving problems by working on a project. It is important to emphasize that simulations are only a tool, so they must be inserted in an appropriate methodology to exploit their advantages [7] – [9]). In this case, given the course modalities and structure, the researchers opted to apply the Modified ILD [10] in combination with PhET simulations [11], [12] ILD aims to foster conceptual learning through hands-on activities and group discussions by transforming passive classrooms into dynamic, participatory environments. In this model, students engage with physical phenomena through teacher-led experiments, followed by collaborative analysis and conclusion drawing.

While simulations such as PhET offer valuable learning opportunities, their effectiveness hinges on integrating within a suitable pedagogical framework [7], [12] - [14]. One such framework is the ILD; however, given the resources and structure of the course, a modified version of ILD is implemented. It is crucial to recognize that while simulations such as PhET offer valuable learning experiences, they are just one component of effective teaching methodologies [7], [12]. Simulations must be integrated into appropriate instructional frameworks to capitalize on their benefits fully.

This research uses the Modified ILD methodology to investigate the impact of PhET interactive simulations on students enrolled in a general physics course for the second time. Specifically, we seek to assess the effectiveness of this approach in enhancing students' understanding of electricity-related concepts and their overall satisfaction with the learning experience.

To guide our study, we have formulated the following research questions:

- What are students' perceptions regarding using PhET simulations within the Modified ILD methodology?
- Are achievements observed in the learning objectives related to electricity using PhET simulations?

Methodology

This research uses quantitative methodology. Students participated in assessments using an inventory focused on electrical concepts, and a survey was conducted to assess perceptions of using PhET interactive simulations as a teaching resource.

Context and participants

This study was conducted in a one-semester general physics course at the university level in a private university in Chile. The main topics covered in the course are kinematics, thermodynamics, electric circuits, and waves. Lecture time is in-presence modality (3 hours per week), and the workshop is offered online (1.5 hours per week). Workshops are not mandatory; thus, the sessions are recorded. However, students must attend or watch (video recording of the session) at least 70% of the workshops.

In the semester this study took place (August-December 2023), all students enrolled in the course had failed the course in the past. This is at least the second time the students have taken this course. The workshops were designed to offer an alternative teaching-learning strategy for the students. Since students who repeat a course tend to miss classes under the assumption that they have already seen or done the activities of the workshops, teachers and designers planned the activities using a teaching strategy (modified ILD) and incorporated technology (Phet simulations) to make the physics course more engaging for the students [15].

The innovative design was based on a positive previous experience in which Phet Simulations were introduced under a modified version of the ILD methodology. Figure 1 shows a schematic view of the roles, activities, and modalities for the innovation sequence implemented. Notice that this instructional strategy requires both individual reflection and group discussion, taking advantage of each technique [16].

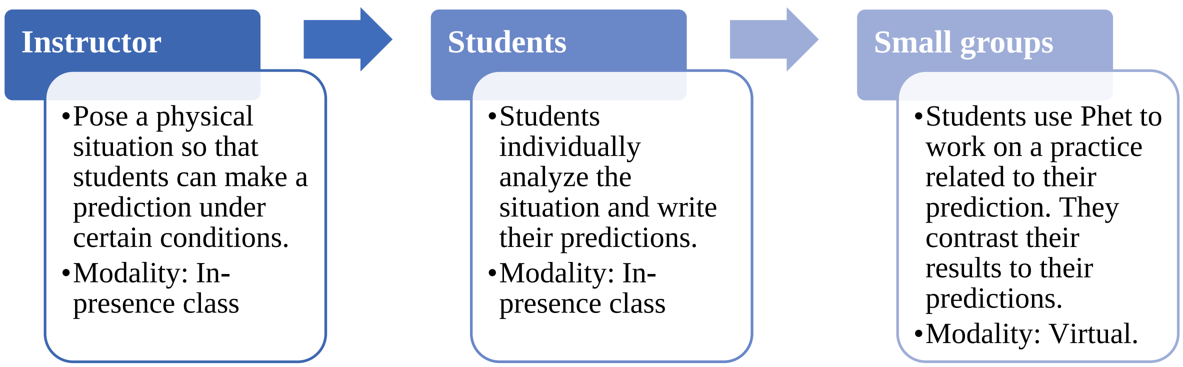


Figure 1. Schematic view of the innovation implemented and the modality.

The regular resources for this course were adapted to the innovation (Modified ILD + Phet) prior to the beginning of the course to have a balanced and clear picture of the topic, activities, number of sessions to introduce the innovation, assignments, and test days. The topic that this study focuses on is the last four weeks of the semester. The topics were electric charges, Coulomb law, electric potential, electric field, and circuits. Students' difficulties in understanding electric circuits have been documented [16]. This gives us another reason to modify the traditional way the course was taught to engage students and foster their learning.

Two groups of the physics course participated in this study, with 25 and 20 students registered). Both instructors were familiar with the use of Phets as well as the implementation of the Modified ILD methodology. A total of 33 (about 73%) students responded to the instrument at the end of the course.

Research design

The development of this study proceeded through four distinct phases:

1. **Design and Development of PhET Guides with the Modified ILD Methodology**. Specific instructional guides were meticulously crafted for teaching electrical concepts using the Modified Interactive Lecture Demonstration (ILD) methodology. These guides were meticulously designed to facilitate hybrid learning experiences, accommodating in-person and virtual instruction.

2. **Implementation of Guides in a Virtual and Distance Learning Environment**. The instructional guides were administered to students within a virtual learning environment,

leveraging distance education modalities to ensure the participation of remote learners. This phase aimed to integrate the instructional materials seamlessly with the remote instructional setting, ensuring accessibility and engagement.

3. **Administration of Perception Surveys**. A structured survey instrument was deployed to assess students' perceptions regarding using the PhET guides and the associated instructional methodology. This phase facilitated the collection of valuable insights into students' perceived effectiveness and overall experiences with the implemented teaching approach.

Utilization of Interactive PhET Simulations Applying the Modified ILD Methodology

Incorporating active methodologies into remote science education presents a contemporary challenge, albeit one that can be surmounted through technological innovation. In the context of a general physics lecture course with virtual and remote components, the limited active participation of students prompted a reassessment and enhancement of the virtual workshop environment to enhance the effectiveness of learning electrical concepts. Leveraging technological tools such as interactive PhET simulations [17] – [19] emerged as a pivotal strategy to foster a more engaging and immersive learning experience, harnessing the potential of distance education and active teaching methodologies. Integrating hybrid teaching strategies, encompassing face-to-face and virtual instruction, holds promise for fostering dynamic and meaningful learning engagements.

Integrating active methodologies and the demonstrated efficacy of interactive PhET simulations in educational contexts [20], particularly within hybrid instructional models that seamlessly blend face-to-face and virtual modalities, emerges as a pivotal strategy to reinvigorate student engagement, and enhance learning outcomes in science education. This pedagogical approach is specifically implemented within the virtual workshop environment, primarily focusing on exploring electrical concepts. The Modified Interactive Lecture Demonstration (ILD) method for teaching with PhET simulations is outlined in Table 1.

Elaborating on some points presented in Table 1, the prediction sheet is handed out as homework in the Modified ILD version. That is, students have more time to reflect on and discuss their predictions. The second stage is very similar in both scenarios. Students' predictions can be recorded for formative assessment, attendance, and their own record of thought processes. These predictions are not graded, but attendance and participation are typically acknowledged. In the modified version, this stage is very similar. The instructor conducts a demonstration with measurements (often involving graphs collected with microcomputer-based laboratory tools) displayed or shared on a suitable platform (such as multiple monitors, an LCD, or a computer projector). In the modified ILD methodology, students engage in a group experiment related to the scenario presented by the professor, utilizing PhET simulations. They complete a results sheet, where they are encouraged to write their conclusions and compare them with their predictions.

Table 1. *Original ILD [21] versus Modified ILD using Phets.*

	ILD [21]	**Modified ILD + Phet***
1	The instructor describes and performs the demonstration for the class without data collection.	At the end of the class, the instructor provides a guide containing a scenario related to the content covered in class.
2	Students are instructed to record their individual predictions on a prediction sheet. The sheet is identifiable by each student's name at the top.	Students record their individual predictions on a prediction sheet, identifiable by each student's name at the top.
3	Students engage in small group discussions with one or two peers.	Not applicable.
4	The instructor gathers common predictions from students across the class.	Not applicable.
5	Students document their predictions on the prediction sheet.	Not applicable.
6	The instructor conducts the demonstration and collects measurements for all students to see.	In remote groups, students conduct the experimental activity using PhET.
	Some students present the results and discuss them in the demonstration context. Students may also complete a results sheet mirroring the prediction sheet, which they can take for further review.	Students describe their results on an experimental activity sheet utilizing PhET simulations, which they fill out with their findings and subsequently upload to a designated virtual space.
8	Students (or the instructor) discuss analogous physical scenarios with varying surface characteristics, emphasizing different situations based on the same underlying concepts.	In groups, students describe and discuss their results alongside the predictions made in the previous class, drawing conclusions from the comparison.

*Modified Five-Step ILD Using PhET Simulations.

Next comes the sharing part among the students. The part aims to foster students' argumentation skills. Some of the students present their results and discuss them in the context of the demonstration.

Finally comes the connecting and extending part, where students and the instructor can pose questions or discuss analogous physical situations with some variations. This promotes connecting the lesson with previous sessions or with other contexts. We encourage students to lead the discussion within their small groups first and then open it to the whole group.

Instrument

To evaluate the effectiveness of the innovation, we implemented some questions for a validated conceptual test and a satisfaction survey at the end of the course. The questions for the conceptual understanding were taken from the Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT) [22] version 1.2, translated into Spanish.

According to the test implementation recommendations, we asked students to take the full test but did not check for correctness as part of students' course final grades. However, given the scope and depth of the physics general course, we only focus on those items covered in the course using the implemented innovation (Modified ILD + Phet simulations).

The satisfaction survey was a Likert-type question. It had two parts, one regarding their general opinion of the innovation implemented (5 item, 4 scale Likert-type scale), and the other more specific aspects of the methodology (9 item, 5 Likert-type scale). The objective of this survey was to give feedback to the course designers and the instructors.

Results and discussion

The results are divided into conceptual understanding (DIRECT results) and students' perception of the innovation. To present the conceptual understanding test result, we group the Likert-type statements into categories to help us interpret respondents' opinions regarding the innovation.

<u>DIRECT results</u>

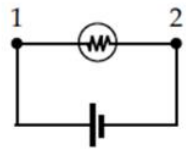
We are organizing the presentation of our results by dividing the items into categories according to [22].

Current

The initial category under consideration pertains to the concept of current. Two specific components are identified within this category: Item 8 and Item 17. Students must grasp the fundamental notion that electric current originates from the battery, traverses along the conductive pathways provided by wires, and proceeds through various circuit elements, which may include resistors or light bulbs, until reaching the opposite terminal of the battery. Moreover, students should comprehend that at designated points known as nodes, the current undergoes division, at which portions of it diverge along separate wire paths. Consequently, all the current traverses the circuit, interfacing with each element therein, before returning to the battery's terminal on the opposite end.

Figure 2 illustrates Problem 8, wherein a schematic representation depicts the arrangement of a bulb interconnected with a battery. The question pertains to comparing the electric current at Point 1 and Point 2, situated at the bulb's terminals. Participants in this educational program must grasp that the magnitude of electric current at Point 1 is the same as that at Point 2. This claim is demonstrated by the principle that the entirety of the current emanating from the battery necessitates passage through Point 1, going through the bulb's filament, and ultimately arriving at Point 2. After Point 2, the current circuitously returns through the battery again. Students' responses are distributed at the left, adjacent to each option.

8) Compare the current at point 1 with the current at point 2. At which point is the current LARGEST?



21% (A) Point 1

6% (B) Point 2

45% (C) Neither, they are the same. Current travels in one direction around the circuit.

27% (D) Neither, they are the same. Currents travel in two directions around the circuit.

Figure 2. Problem 8 falls into the current category.

The findings reveal that most students selected the correct response (option D: neither, they are the same). However, only 45% chose the correct reasoning (current travels in one direction around the circuit). A subset of students opted for option D, while others chose option A. Those students who selected option D indeed chose the correct answer, which asserts that the electric current remains consistent throughout the circuit. However, their rationale for this choice posits that the current flows in dual directions within the circuit. This reasoning may stem from pedagogical practices, as instructors commonly discuss the directional flow of current in the classroom. According to conventional current, electric current originates from the battery's positive terminal, traverses the circuit, and returns to the negative terminal. Conversely, in electronic current theory, the flow is conceived to begin at the negative terminal, circulate through the circuit, and arrive at the positive terminal. Thus, the instructional approach adopted by the teacher may have influenced students' inclination towards this option.

As previously noted, the third most frequently selected option is the letter A. This implies that students perceive the electric current at Point 1 to be greater than that at Point 2. Such a misconception may arise from the erroneous belief among students that electric current is expended within the circuit. This misconception postulates that the current flowing through Point 1 diminishes upon passing through the bulb, where a portion of the current is supposedly consumed to illuminate the bulb. Consequently, the residual current at Point 2 is anticipated to be diminished.

Figure 3 illustrates Problem 17, the second question within the "current" category. Like Problem 8, this question presents a scenario where a second bulb is connected in parallel to the first bulb. Participants are tasked with ranking the electric current at six designated points denoted as 1, 2, 3, 4, 5, and 6. As with the preceding question, the necessity for the electric current originating from the battery's positive terminal to return to the negative terminal mandates that the current at point 5 equals that at point 6. In this instance, students must grasp that upon reaching the junction of multiple wires, the current undergoes division, the extent of which is not uniformly halved. Notably, since both bulbs are subjected to an identical potential difference, the current through point 1 mirrors that through point 3. Conversely, the sole pathway for the current at point 1 is through point 2, like the exclusive path for the current at points 3 through 4. Consequently, the greatest currents are at points 5 and 6, while the currents at points 3 and 4 and at points 1 and 2 remain equivalent. Hence, option D emerges as the correct response. Students' responses are distributed at the left, adjacent to each option.

17) Rank the currents at points 1, 2, 3, 4, 5, and 6 from HIGHEST to LOWEST.

36% (A) 5, 3, 1, 2, 4, 6

12% (B) 5, 3, 1, 4, 2, 6

42% (C) 5 = 6, 3 = 4, 1 = 2

6% (D) 5 = 6, 1 = 2 = 3 = 4

3% (E) 1 = 2 = 3 = 4 = 5 = 6

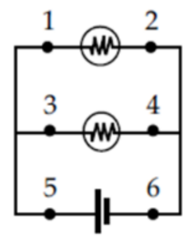


Figure 3. Problem 17 is the second question in the current category.

The findings indicate that merely 6% of the students accurately selected the correct answer. Notably, 42% of respondents opted for option C, indicating an understanding among students that the current at points 5 and 6 are equivalent, consistent with the conclusions drawn from Question 8. Additionally, students may have recognized the equivalence between the currents at points 3 and 4 and at points 1 and 2, as the current follows a singular path. However, a notable oversight among students is their failure to discern that the current at point 3 should not surpass that at point 1. Instead, it should be identical, given that the potential difference across the bulbs' terminals is the same.

Upon examining these two questions regarding current flow, a heterogeneous response pattern emerges. While the majority accurately responded to Problem 8, a minority achieved the correct answer to Problem 17. This suggests that students possess a foundational understanding of current principles, comprehending that the current remains constant within a circuit when constrained to a single pathway. However, this understanding appears to falter when applied to the entirety of the circuit, leading to inaccuracies in response.

Potential difference (voltage)

The central concept in this category is potential difference. Students must grasp that potential difference inherently exists between two distinct points within a circuit and is not transmitted through the wires themselves. This category comprises two specific items, namely Question 6 and Question 28.

Problem 6, depicted in Figure 4, illustrates a circuit featuring two bulbs connected in series to a battery, with five designated points along the circuit's path. The task entails ranking the potential difference between points 1 and 2, 3 and 4, and 4 and 5 within the circuit. Notably, the potential difference of the battery is allocated between the potential difference between points 3 and 4 and the potential difference between 4 and 5. Moreover, owing to the equivalence in current flowing through both bulbs, the potential difference between points 3 and 4 mirrors that between points 4 and 5. Consequently, option E emerges as the correct response. Students' responses are distributed at the left, adjacent to each corresponding option.

6) Rank the potential difference between points 1 and 2, points 3 and 4, and points 4 and 5 in the circuit shown below from HIGHEST to LOWEST.

27% (A) 1 and 2; 3 and 4; 4 and 5

15% (B) 1 and 2; 4 and 5; 3 and 4

3% (C) 3 and 4; 4 and 5; 1 and 2

27% (D) 3 and 4 = 4 and 5; 1 and 2

27% (E) 1 and 2; 3 and 4 = 4 and 5

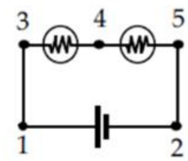


Figure 4. Problem 6 of potential difference.

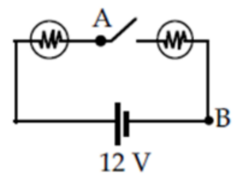
The findings indicate that only one-third of the students accurately chose the correct answer. Remarkably, the two other options garnered an equal selection percentage, with D and A receiving comparable responses. Option A partially aligns with the correct response, acknowledging that the potential difference between points 1 and 2 is the highest. However, some students erroneously perceived the potential difference between points 3 and 4 to surpass that between points 4 and 5, potentially influenced by a misconception regarding the flow of potential differences within the circuit. This misunderstanding may stem from confusing the concepts of potential difference and electric current.

Conversely, students who opted for option D correctly identified that the potential difference between points 3 and 4 equates to that between points 4 and 5. Nonetheless, they mistakenly asserted that these potential differences exceeded the potential difference between points 1 and 2, whereas, in reality, the potential difference between points 1 and 2 is the highest.

Figure 5 illustrates Problem 28, featuring a circuit configuration where a 12-volt battery is connected to two bulbs arranged in series. However, a switch located at point A remains open. In this scenario, students are tasked with comprehending that an open switch prevents any current flow within the circuit. The problem prompt requests explicitly the determination of the potential difference between points A and B. Given that point B is directly linked to the negative terminal of the battery, while point A is directly connected to its positive terminal, the potential difference between points A and B equates to the battery's voltage, which is 12 volts.

To grasp this concept, students must recognize that the potential difference across its terminals is zero in the absence of current flow through the left bulb due to the open switch. Thus, point A is directly linked to the battery's positive terminal. Students' responses are distributed at the left, adjacent to each option.

28) What is the potential difference between points A and B?



25%	(A) 0 V
13%	(B) 3 V
34%	(C) 6 V
19%	(D) 12 V
5%	(E) None of the above

Figure 5. Problem 28 of potential difference.

The findings indicate that only 19% of the students correctly selected the answer. Notably, 34% of students chose option C, 6 Volts, which would be accurate if the switch were closed. This suggests that these students lack understanding regarding the switch's function. Additionally, 25% of students selected option A, 0 Volts. While these students may grasp the operation of a switch and recognize the absence of current in the circuit, they may erroneously assume that the potential difference between points A and B is also zero due to the lack of current flow. This oversight arises from overlooking the direct connection of these points to the battery.

The outcomes of the two potential difference problems underscore the complexity of this concept for students. Problem 6 highlights confusion between potential difference and current, while Problem 28 reveals a misunderstanding of the potential difference between two points. Students often conflate these concepts with current ones, leading to misconceptions.

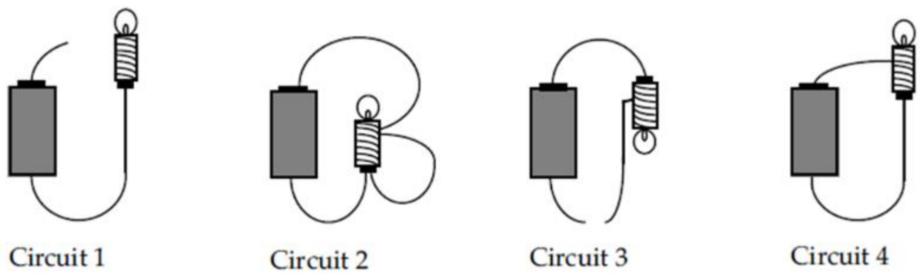
Schematic representation

Two problems, labeled Problems 18 and 22, are presented within this category. These problems feature circuit diagrams with realistic depictions of circuit elements rather than abstract symbols. Students must recognize that each element within the circuit possesses two distinct ends. In these particular problems, the circuits consist solely of bulbs and batteries.

In the case of batteries, their two ends are represented by the top and bottom sides, with the positive end typically depicted as darker and smaller. However, for bulbs, the representation is more intricate. Students must discern that the ends of the bulbs are not located at the extreme edges but rather comprise one side (typically darker than the rest) and the threaded portion on the bulb's side.

Figure 6 explicitly portrays Problem 18, featuring four circuit sketches prompting students to identify which circuit configuration illuminates the bulb. To respond accurately, students must comprehend the necessity for a closed circuit to enable bulb illumination. Furthermore, the closure of the circuit must involve both ends of the circuit elements. Students' responses are distributed at the left, adjacent to each option.

18) Which circuit(s) will light the bulb?



9% (A) Circuit 1

9% (B) Circuit 2

36% (C) Circuit 4

42% (D) Circuits 2 and 4

3% (E) Circuits 1 and 3

Figure 6. Problem 18 with four circuits.

A closed circuit is essential for illuminating the bulb, so the correct solution lies between circuits 2 and 4. However, it is imperative that the circuit employs the ends of the elements effectively. In the case of circuit 4, the arrangement ensures that the current flows from the battery through the bulb and then returns to the battery, constituting a proper circuit configuration. Similarly, circuit 2 also utilizes both ends of the elements. However, in this arrangement, the current travels through the wires all the way back to the battery without passing through the bulb, rendering it ineffective in illuminating the bulb. Consequently, the correct answer is option C, which 36% of students chose. The second most selected option is D, which includes circuit 4, the correct configuration, and circuit 2. Although circuit 2 forms a closed circuit, it fails to light the bulb as the current bypasses it.

Figure 7 shows Problem 22, presenting a circuit diagram featuring a battery interconnected with four bulbs arranged in series, depicted in symbolic representation. The objective is to identify which of the four options represents the same circuit when depicted realistically. As mentioned, students must grasp the necessity for a closed circuit, ensuring that wires connect both ends of the elements and that the current flows through each element.

With these considerations in mind, circuits 2 and 4 are not feasible options, as some bulbs within them lack connections to both ends. On the other hand, circuits 1 and 3 remain plausible, as they utilize both ends of the elements, allowing the current to pass through the bulbs. However, in circuit 1, the current flows from the positive end of the battery through two bulbs before returning to the battery. In contrast, the symbolic circuit indicates that the current passes sequentially through all four bulbs. Hence, circuit 3 accurately represents the question, rendering option B the correct answer. Students' responses are distributed at the left, adjacent to each option.

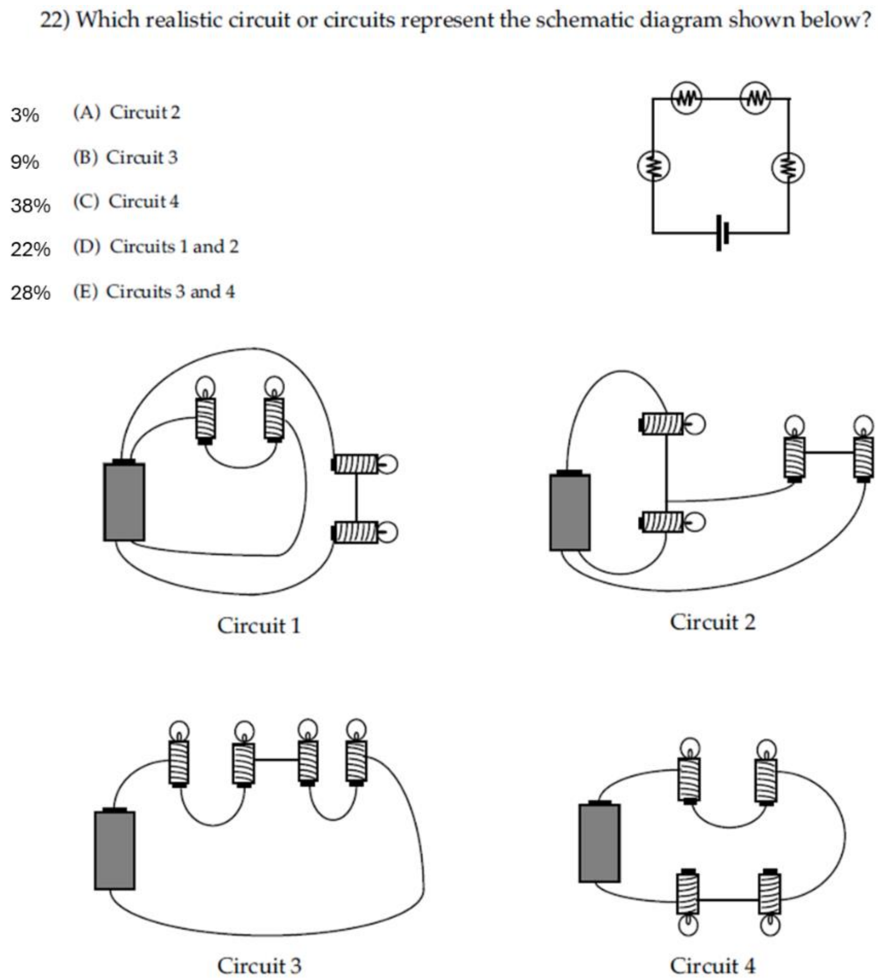


Figure 7. Problem 22 with four circuits.

The findings indicate that only 9% of students accurately identified the correct answer. The primary source of confusion arises from circuit 4, which closely resembles the arrangement of the realistic circuit representation, thereby leading to its perceived correctness. Notably, 38% of students opted for option C, solely comprising circuit 4. Additionally, option E, which includes circuit 4, was chosen by 28% of students.

These results underscore the challenges students face in interpreting realistic circuit representations. Students engaging with physical circuits during classroom activities tend to perform better on this type of question. Moreover, those utilizing PhET simulations may encounter difficulties visualizing real equipment, making the interpretation of realistic representations more challenging [18], [23].

<u>Students' perception of the innovation</u>

We implemented a survey to gather the students' perceptions of their experience using the Phet simulations and working in groups during the workshop part of the course. The questions were divided into groups: one focused on the frequency of certain topics about the use of Phet sims (Table 2), and the second part was statements to respond in an agreement-disagreement scale (Table 3).

Table 2. Percentage of responses on the use of the Phet simulation.

Question	Never	Some-times	Almost always	Always
1. Did you have any difficulties when working with the PhET simulators?	46%	**46%**	4%	4%
2. Did you find the activities proposed in the PhET simulators friendly?	0%	21%	25%	**54%**
3. Did the electricity activities help you better understand the concepts and thus strengthen your learning?	4%	21%	**42%**	33%
4. Were the instructions for the activities to be carried out in the PhET simulators clear?	0%	17%	38%	**46%**
5. Did you find using electricity activities in the PhET simulators attractive/motivating?	4%	25%	13%	**58%**

Questions 1, 2, and 5 of Table 2 indicate that even though students may have encountered some difficulties with the technology, it was not very often and turned out to be a friendly application and even a motivating activity for learning. Most students considered that almost always (42%) or always (33%) the design of the activities promoted their understanding of the topic. These results are consistent with the second part of the survey (Table 3). The percentage of responses for questions 6, 7, and 11 indicate that students found the simulation tool a helpful resource in their learning, and about 60% of the participants consider that its use should be increased.

Table 3. Percentage of responses on the general aspects of the course based on the innovation.

Statement	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
6. I consider that my skills improved with this tool.	29%	**38%**	13%	17%	4%
7. The simulations provided a clear idea of the studied phenomena.	33%	**38%**	21%	4%	4%
8. The number of activities to work on in the simulations was excessive.	4%	8%	25%	**33%**	29%
9. The instructions for using Phet were not completely clear.	4%	8%	17%	**50%**	21%
10. Cannot work well with the simulator due to connection problems.	4%	8%	17%	13%	**58%**
11. I think more work should be done with the Phet simulation.	**42%**	17%	17%	17%	4%

There were three negative questions, 8, 9, and 10, and consistently, most students disagreed on the Phet simulation activities being excessive or difficult to use or work on. We highlight this because the participants were taking the course for the second time; these activities helped them engage, allowing them to perceive an improvement in their skills related to the content.

Conclusions

Summarizing, we establish the four main results of this study.

1. The evidence suggests that while students demonstrate a fundamental grasp of current principles, their comprehension falters when extrapolating this understanding to encompass entire circuits, resulting in inaccurate responses. This indicates a need for targeted interventions to bridge the gap between conceptual knowledge and its application within complex circuit configurations.

2. The analysis of potential difference problems highlights the intricacies of this concept for students, revealing common confusions between potential difference and current and misconceptions regarding the potential difference between two points. These findings underscore the necessity of tailored instructional strategies to address these misconceptions and enhance conceptual clarity.

3. The findings emphasize students' difficulties when interpreting realistic circuit representations. Students utilizing PhET simulations may face challenges in visualizing real equipment, complicating their ability to interpret realistic representations effectively. Addressing these challenges requires innovative teaching approaches that integrate diverse instructional tools and provide ample opportunities for hands-on learning experiences.

4. From the opinion survey, we gather that students like using Phet and consider it helpful in their learning.

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