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THE USE OF PHET COLORADO AS A PEDAGOGICAL RESOURCE FOR TEACHING ELECTRICAL CIRCUITS IN HIGH SCHOOL

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Silvio Luiz Rutz da Silva[1] and Ivo Patel[2]

ABSTRACT

The study addresses the central question of how to overcome the limitations of traditional teaching of electrical circuits in high school, especially in contexts with limited laboratory resources. The objective is to investigate the effectiveness of the PhET Colorado simulator as a pedagogical tool to facilitate the understanding of electrical circuit concepts, promoting an interactive approach that combines theory and practice. The research was applied to a third-year high school class, where students were able to manipulate variables such as resistance and voltage in circuit simulations, favoring the understanding of complex concepts such as Ohm's Law. The main results indicate that PhET Colorado not only facilitates the understanding of the contents, but also stimulates the protagonism and critical thinking of students, actively engaging them in the learning process. Interactive simulation proved to be effective for the development of cognitive skills and greater retention of content, overcoming the limitations of traditional expository methodologies. It is concluded that the PhET is an accessible and inclusive tool, which democratizes the teaching of Physics by providing a practical and meaningful experience, aligned with the demands of contemporary education. As future perspectives, the study suggests the exploration of PhET in other areas of Physics and the integration with collaborative methodologies, such as problem-based learning, to further enrich scientific teaching and encourage the exchange of knowledge among students in an interactive environment and critical reflection.

Keywords: Interactive Learning. Experimental Teaching. Virtual Simulation. Active Methodologies. Student Engagement.

[1] Dr. in Materials Science – UFRGS – RS; 2001
Department of Physics; Graduate Program in Physics Teaching – National Professional Master's Degree in Physics Teaching – Pole 35; State University of Ponta Grossa
E-mail: rutz@urpg.br
ORCID: https://orcid.org/0000-0003-1859-9018
LATTES: http://lattes.cnpq.br/2928452720980161
[2] Degree in Physics Teaching – UNOESTE – SP; 1999
State Department of Education – PR
Graduate Program in Physics Teaching – National Professional Master's Degree in Physics Teaching – Pole 35; State University of Ponta Grossa
E-mail: ivopatel@hotmail.com
ORCID: https://orcid.org/0009-0006-5431-6598
LATTES: http://lattes.cnpq.br/1896565793762178

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INTRODUCTION

The proposal for methodological innovation in the teaching of Physics is an emerging demand for the contemporary educational environment, which faces challenges in the effective understanding and application of scientific content by students. In Brazil, traditional teaching methodologies have shown limitations in keeping up with the pace of social and technological transformation, limiting students' ability to perceive the relevance of Physics in their daily lives (Gomes et al., 2020).

The study of electrical circuits is an essential subject of physics. Due to its theoretical complexity, this topic often challenges students' understanding. This context calls for new approaches that combine theory and practice, promoting more solid and applicable knowledge (Rosenthal and Henderson, 2006; Zacharia, 2007; Akdemir, 2015).

Within this scenario, the use of active methodologies, which involve the student as the protagonist of their learning, emerges as an efficient strategy to promote meaningful learning. According to Vygotsky (1991, 2000, 2002), knowledge is built in interaction with the environment and with the other, which reinforces the relevance of methodologies that prioritize experimentation and the active participation of students (Karpov, 1995; Jaramillo, 1996; Newman and Latifi, 2020).

The use of digital resources, such as simulators, allows the application of these methodologies even more effectively, expanding the possibilities of interaction and immersion of students in the content covered. Practice with technologies such as PhET Colorado, an interactive simulation platform for the study of electrical circuits, contributes to making the teaching process more engaging and accessible (Vick, 2010; Masruroh et al., 2020). This resource allows students to experiment, in a safe and dynamic way, fundamental concepts of Physics, developing cognitive skills of analysis and problem solving (Coelho, 2002).

The main objective of the study of the use of PhET Colorado in the teaching of electrical circuits is to verify how this technology can facilitate the learning process for high school students. PhET, developed by the University of Colorado, offers a wide range of interactive simulations that cover several areas of science, such as Physics, Biology and Chemistry, being an innovative and accessible tool (Wieman, 2007).

In teaching electrical circuits, PhET allows for the creation of simulated environments where students can manipulate variables, observe circuit behaviors in different configurations, and build a deeper understanding of concepts such as electric current,

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resistance, and voltage (Lee et al., 2015; Masruroh et al., 2020; Bantolo and Mistades, 2021; Anisa and Astriani, 2022).

In this way, the use of PhET Colorado provides learning that goes beyond the memorization of formulas and abstract concepts, facilitating the application of content in practical and everyday situations, aligning with the objectives of a modern and interactive education. They facilitate the practical application of the contents, increase students' interest and motivation, and develop scientific and 21st century skills. In addition, they are flexible and accessible tools, effective in both face-to-face and remote teaching, contributing significantly to the improvement of students' academic performance. (Perkins et al., 2006; Wieman, 2007; Petrova, 2020).

The justification for the adoption of PhET Colorado in the teaching of electrical circuits is anchored in the need for strategies that combine theory and practice in the same educational context, promoting the formation of fundamental scientific skills. Interactive simulations improve conceptual understanding, are accessible and easy to use, can replace real labs, and result in superior academic performance. Therefore, the integration of PhET into Physics classes is an effective strategy to promote quality science education. (Vick, 2010; Najib et al., 2022; Fuada et al., 2023; Wirda et al., 2023).

In addition, PhET's interactive simulations attract and maintain students' interest, offering a learning experience that encourages autonomy and critical thinking. This methodology meets the demands of current education, valuing the preparation of students to face real problems in a creative and analytical way (Wieman et al., 2008; Khaeruddin and Bancong, 2022; Rayan, et al., 2023).

Active methodologies, based on approaches such as discovery learning, have been shown to be effective in developing cognitive skills and retaining knowledge. Bruner (1961) states that meaningful learning occurs when the student is encouraged to discover concepts by himself, which generates greater engagement and understanding.

The use of PhET Colorado follows this principle by allowing students to explore physical phenomena in an interactive way, experimenting with different settings and outcomes. This methodology transforms the student from a passive receiver to an active agent of the learning process, encouraging participation and the formulation of hypotheses (Prince, 2004). Thus, by combining practice with theory, PhET Colorado presents itself as an essential tool to consolidate the understanding of electrical circuits and other complex topics in Physics (Vick, 2010; Fuada et al., 2023).

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In the context of learning electrical circuits, the interactivity provided by PhET Colorado allows students to experiment in a safe environment, allowing them to manipulate variables such as voltage, current, and resistance (Vick, 2010; Fuada et al., 2023). According to Wieman et al. (2008), the use of simulators in science education improves students' performance and understanding, since simulations contribute to the fixation of content through repetitive and adjustable experiences.

At PhET Colorado, students can, for example, create circuits in series or in parallel, test the impact of adding new elements, and observe how the behavior of the circuit is changed. This practice provides a clear visualization of physical phenomena, strengthening the understanding of fundamental principles, such as Ohm's Law, which are essential for the study of electrical circuits (Vick, 2010; Fuada et al., 2023).

Another relevant aspect of PhET Colorado is its ability to make learning more inclusive and accessible, especially in contexts of structural inequality. Many schools face difficulties in providing sufficient resources for practical activities, and the use of digital simulators is an efficient and cost-effective solution to this situation (Perkins et al., 2006; Moore et al. 2014).

Wieman (2007) highlights that the use of simulators in science teaching makes the content more accessible to students of different contexts and abilities, promoting a democratization of scientific knowledge. PhET Colorado is a free tool that can be used both in the classroom and in virtual environments, expanding the reach of educational activities and allowing the teaching of Physics to be within the reach of more students (Perkins et al., 2006; Sotiriou et al., 2010; Saudelli et al., 2021).

PhET Colorado's ability to adapt to each student's pace and individual needs is another factor that reinforces its usefulness as a pedagogical tool. With the simulator, students can explore concepts at their own learning speed, revisiting content and experimenting with new circuit configurations as many times as necessary to consolidate knowledge (Salunke and Vijayalakshmi, 2016; Alsadoon et al., 2017; Dhang and Kumar, 2023).

This flexibility stimulates the autonomy and responsibility of students in the learning process itself, which, according to Bruner (1961), is fundamental for the formation of solid scientific thinking. In a world increasingly focused on knowledge and innovation, this methodology contributes to the development of skills that are essential to the current context (Laar et al., 2017).

In summary, the use of PhET Colorado in the teaching of electrical circuits represents an effective alternative to overcome the limitations of traditional approaches, promoting a more dynamic, interactive and inclusive teaching of Physics (Vick, 2010; Masruroh et al., 2020; Bantolo and Mistades, 2021; Burde et al., 2022).

The methodology applied through PhET integrates the principles of active methodologies and discovery learning, providing an educational experience that goes beyond simple theoretical exposition. The involvement of students in the experimentation and manipulation of concepts in a simulated environment allows them to build knowledge based on practice, consolidating learning and preparing them for the application of these concepts in real contexts (Coelho, 2002).

It is concluded, then, that the use of technological tools such as PhET Colorado in the teaching of Physics not only facilitates the understanding of the contents but also arouses the interest and engagement of students in the learning process (Perkins et al., 2006; Wieman et al., 2008; Pranata, 2023).

The central question that this research seeks to answer is related to the challenges faced in teaching electrical circuits in physics to high school students. Traditionally, physics teaching in Brazil has been based on expository methods and mechanical memorization practices that often limit students' ability to relate theoretical content to the world around them (Bezerra et al., 2011).

The difficulty of students in understanding electrical circuits, for example, is amplified by the absence of approaches that promote practical and interactive experimentation, making it difficult to understand fundamental concepts such as voltage, current and resistance. In addition, many school contexts do not have adequate laboratories or physical resources to carry out practical experiments, which restricts opportunities for practical and interactive learning (Lowe et al., 2013; Daba et al., 2016; Nawaz, 2022).

Given these difficulties, there is a need to investigate whether the use of technological resources, such as the PhET Colorado simulator, can contribute to overcoming the limitations imposed by the lack of infrastructure, while providing a more dynamic and accessible teaching experience. Thus, the question that guides this study is: "How can PhET Colorado be integrated into the teaching of electrical circuits to promote more meaningful and interactive learning, overcoming the structural and methodological limitations present in schools?"

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The objective of this research is to investigate the potential of the PhET Colorado simulator as a pedagogical tool to facilitate the teaching and learning of electrical circuits in high school, promoting an approach that unites theory and practice in an environment of interaction and virtual experimentation.

Specifically, the research aims to design and apply a didactic unit based on the use of PhET Colorado, observing the cognitive development of students in the topic of electrical circuits and analyzing how simulation can influence the understanding of concepts such as current, resistance and voltage.

THEORETICAL FOUNDATION

The use of simulations and active methodologies in teaching has gained relevance, especially in disciplines that require practical experimentation, such as physics. In the current educational context, the search for alternatives that provide more interactive and contextualized learning has intensified (Rutten et al., 2015; Ceberio et al., 2016; Kumar and Tiwari, 2018; Ogegbo and Ramnarain, 2022).

Digital simulations and methodologies that involve the student as the protagonist of the learning process represent a necessary adaptation to the transformations of the educational scenario (Wieman et al., 2008; Chernikova et al., 2020).

These methods are based on the active construction of knowledge, where the student is not only a receiver, but an agent who investigates and interprets phenomena. According to Gomes et al. (2020), the use of interactive technologies in the classroom allows students to explore simulated situations, developing cognitive skills that go beyond memorization.

Simulations provide a practical alternative to physical experimentation, which is often not feasible in school settings due to infrastructure constraints. By creating learning environments that combine theory and practice, digital simulations contribute to a more complete education adapted to contemporary demands (Rutten et al., 2012; Psotka, 2013.).

One of the main theoretical foundations for the use of interactive simulations in education is Vygotsky's (1991, 2000, 2002) sociointeractionist theory, which proposes that learning occurs more effectively in social contexts.

According to Vygotsky (1991, 2000, 2002), learning is a process mediated by social interaction and the cultural context in which the individual is inserted. Through this mediation, the student is able to internalize knowledge in a more meaningful way, building

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cognitive skills that meet the demands of the environment in which they live (Poehner and Infante, 2017; Guo, 2020).

In the teaching of physics, this theory underpins the importance of methodologies that allow interaction between the student and knowledge, so that he can experiment, question, and construct meanings in relation to the contents studied (Candido et al., 2022; Ogegbo and Ramnarain, 2022).

Digital simulation is a tool that, by creating a controlled and interactive environment, allows the student to interact with knowledge in a similar way to the social interaction proposed by Vygotsky (1991, 2000, 2002), favoring active learning and the development of problem-solving skills (Oliveira et al., 2022).

Vygotsky's theory (1991, 2000, 2002) introduces the concept of zone of proximal development (ZPD), which represents the distance between what a student can do alone and what he can accomplish with help. This zone is essential to understand how the use of simulations can expand students' learning capacity.

In interactive simulations, the student has the opportunity to explore the content in a practical way, facing challenges that are located in this zone, which enables more effective learning (Vygotsky, 1991, 2000, 2002). By manipulating variables and observing the effects of their choices, the student builds knowledge progressively, moving from dependence on direct instruction to autonomy.

This process is intensified in physics simulations, where the student can safely experiment with complex concepts such as voltage and electric current, thus overcoming the limitations of passive learning and promoting the construction of applicable scientific skills (Başer, 2006; Moya, A., 2018).

Active methodologies, which are complementary to Vygotsky's theory (1991, 2000, 2002), have gained space in the teaching of science as practices that allow students to act as protagonists of their learning. In the teaching of physics, these methodologies transform the expository approach, common in traditional classes, into an investigative process where the student explores concepts and solves problems in a practical way (Obioma, 1986; Etkina et al., 2020).

According to Prince (2004), active learning is a strategy that involves the student in activities that require reflection, experimentation and decision-making, promoting greater engagement with the content. In the context of electrical circuits, for example, instead of just listening to an explanation of Ohm's Law, the student is encouraged to apply it in a

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simulation, where he can manipulate the voltage and resistance variables to observe the direct effects on the current. This practice facilitates the understanding of abstract concepts, making learning more intuitive and aligned with students' cognitive demands (Đorić et al., 2019; Varganova and Kolomiiets, 2023).

The use of simulations in physics teaching allows the student to have a learning experience similar to that of a physical laboratory, but with the advantage of the interactivity and security offered by the virtual environment (Snir et al., 1993; Wirda et al., 2023). Studies such as that of Wieman et al. (2008) highlight that digital simulations are effective in increasing student engagement, providing a deeper understanding of science concepts.

In teaching electrical circuits, simulations allow students to see, in real time, how different circuit configurations influence current and voltage distribution, which broadens their understanding of the content (Manunure et al., 2019; Burde et al., 2022).

In addition, simulations provide the student with the opportunity to explore different hypotheses, manipulating variables and observing the consequences of their choices. This freedom to experiment promotes the development of critical and scientific thinking, essential aspects for the formation of solid and applicable knowledge (Rivers and Vockell, 1987; O'Flaherty and Costabile, 2020; Khaeruddin and Bancong, 2022).

PhET Colorado is one of the most widely used simulators for science education and is especially well suited for teaching electrical circuits. Developed by the University of Colorado, PhET offers a series of interactive simulations that cover content such as physics, chemistry and biology, with an intuitive and accessible interface (Wieman et al., 2008; Sotiriou et al., 2010; Vick, M., 2010; Fuada et al., 2023).

According to Wieman (2007), the goal of PhET is to transform science education, providing a learning environment that is dynamic and engaging for students. In the case of teaching electrical circuits, PhET allows students to assemble circuits in series and parallel, test different configurations, and observe the impact of changes immediately. This approach provides a practical understanding of the concepts, facilitating the retention and application of the content learned in everyday situations (Masruroh et al., 2020; Dantic and Fluraon, 2022).

PhET Colorado's features are especially useful for students who do not have access to well-equipped physics labs. By using the simulator, students can perform virtual experiments that replicate the conditions of a physical laboratory, but without the limitations and risks associated with this environment (Vick, 2010; Lutfiani et al., 2023; Wirda et al., 2023).

Gomes et al.(2020) note that the use of simulators such as PhET represents a viable alternative for schools with limited infrastructure, offering a cost-effective and efficient solution for practical experimentation. In PhET, the student can explore circuits with different types of components, manipulating elements such as resistors, batteries and conductive wires, which allows a clear visualization of the phenomena and facilitates the understanding of fundamental concepts, such as current flow and resistance (Engelhardt and Beichner, 2003; Lee et al., 2015).

Another advantage of PhET Colorado is its accessibility and ease of use, features that extend the reach of this tool to different educational contexts. The simulator is free and available in several languages, including Portuguese, which makes it feasible to use in public and private schools (Perkins et al., 2006; Sotiriou et al., 2010; Perkins et al., 2015; Perkins and Moore, 2018).

In addition, PhET is designed to be intuitive, which makes it possible for students of different ages and levels of knowledge to use it without difficulty. Wieman (2007) points out that the simplicity of the PhET interface facilitates the inclusion of students who might otherwise encounter barriers in understanding physics content (Hasibuan and Abidin, 2019; Uwamahoro et al., 2021; Susilawati et al., 2022).

Thus, PhET not only promotes the learning of concepts but also contributes to a more equitable education, where all students have the opportunity to interact with knowledge in a practical and meaningful way (Wieman et al., 2008; Pranata, 2023; Rayan et al., 2023).

In summary, the integration of interactive simulations and active methodologies in the teaching of physics, based on the theory of Vygotsky (1991, 2000, 2002) and improved by the use of technologies such as PhET Colorado, represents an innovative approach to science education. By combining social interaction, active practice, and virtual experimentation, this methodology promotes well-rounded learning adapted to the needs of contemporary students (Perkins et al., 2006; Wieman et al., 2008; Petrova, 2020; Najib et al., 2022).

The benefits observed in the use of PhET Colorado in the teaching of electrical circuits demonstrate that this tool can provide an accessible, inclusive and effective learning experience, which enhances the development of cognitive skills and prepares students to face scientific challenges in a critical and analytical way (Vick, 2010; Bantolo et al., 2021; Fuada et al., 2023; Wirda et al., 2023).

METHODOLOGY

The methodology described in the dissertation on the use of PhET Colorado for the teaching of electrical circuits in high school was designed to evaluate the effectiveness of the simulator as a pedagogical tool, following an experimental approach in a classroom context.

The research was conducted with ten students from the third year of High School at the Colégio Estadual do Campo João Paulo I – EFM, located in the Regional Education Center of Pato Branco, in the Municipality of Chopinzinho. This choice was made due to the convenience of the institution's proximity to the researchers and the availability of the class to participate in the research.

This choice allowed us to observe the impact of the simulator on students with different learning profiles, evaluating both the cognitive benefits and the challenges faced in the use of a simulation-based methodology.

The development of the methodology included the structuring of a didactic sequence composed of theoretical and practical classes, in which students used the PhET Colorado simulator to explore the principles of electrical circuits. Initially, a theoretical introduction about circuits was made, with an explanation of the fundamental concepts and laws that govern the operation of electrical circuits, such as Ohm's Law.

The first class introduces the project, its objectives, and the schedule, emphasizing student engagement. Then, the second class launches a challenge to stimulate critical thinking. The following classes explore serial and parallel circuits, with hands-on activities and the use of PhET Colorado, allowing students to actively build knowledge according to Constructivist Theory. The last class uses the Quizizz platform to evaluate learning, promoting collaborative feedback.

This planning shows how PhET Colorado, combined with active methodologies, facilitates the understanding of electrical circuits in an interactive and participatory environment. This initial stage was essential to provide students with the necessary theoretical foundation so that they could interact with the simulator autonomously and assertively.

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Chart 1 describes the didactic sequence aimed at teaching electrical circuits using the PhET Colorado simulator as a central tool to integrate theory and practice.

Chart 1 - Didactic Sequence for the Teaching of Electrical Circuits with the Use of the PhET Colorado Simulator.

Class	Description	Teaching Objective
Lesson 01	Introduction to the project: the teacher presented the purpose of the project, methodology, schedule of activities and expected results. He emphasized the importance of everyone's engagement. He explained the relevance of social interaction in cognitive development, encouraging the active involvement of students.	Highlight the importance of social interaction for cognitive development.
Lesson 02	I start with a challenge to stimulate critical thinking and problem-solving. Discussion on how to connect new knowledge to students' existing cognitive structures, making learning more meaningful and linked to previous experiences.	Promote the connection between new knowledge and the cognitive structure of students
Lesson 03	Continuation of the serial association study. The students carried out practical experiments with alternative materials to explore this type of circuit. The professor introduced the PhET Colorado software, demonstrating its functionalities, and the students built circuit models in series. The class concluded with a quiz to consolidate the understanding of the concept.	Enhance the active construction of knowledge by the student through experimentation and exploration
Lesson 04	Focus on the association of resistors in parallel. The students built a circuit in parallel with alternative materials, exploring their characteristics and properties. After the physical construction, they applied the concepts in PhET Colorado to virtual modeling. The class promoted the construction of knowledge through practice and discussion.	Encourage the active construction of knowledge through practical experimentation and reflection.
Lesson 05	Presentation of images of associations in parallel and series to consolidate the concept. Introduction to the mixed circuit, integrating both of the previous types. Students built mixed circuits at PhET Colorado to apply and consolidate the concepts covered.	Promote learning as a process of constructing meanings through interaction with the environment.
Lesson 06	Evaluation of the results and final considerations. Using the Quizizz platform, students participated in an assessment, and the results were discussed in class. This continuous evaluation reinforced the learning and active participation of students in the collaborative construction of knowledge.	Promote collaborative learning.

Source: The Authors

Data collection was based on questionnaires applied before and after the activities with the PhET, with the objective of measuring the evolution in the students' understanding of the subject. Additionally, direct observations were made during the practical activities, where the teacher recorded the students' interactions with the simulator, their reactions and difficulties.

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This data has enabled one of PhET Colorado's impact on learning, highlighting both the development of cognitive skills and the increase in student engagement.

The practical activities were divided into progressive stages, where students were initially introduced to simple circuits in series and, later, to parallel circuits and mixed circuits. During the simulations, the students were able to manipulate variables such as resistance and voltage, observing in real time the changes in the electric current.

This process enabled safe and controlled experimentation, where students could test hypotheses, verify predictions, and understand the relationships between variables. This practical approach aimed to stimulate students' protagonism and promote active learning, encouraging them to build their knowledge through experimentation and critical analysis.

At the end of the activities, a group discussion was held so that students could share their observations and conclusions, promoting a collective reflection on the concepts worked on. This moment was important to consolidate learning, allowing students to articulate their understandings and review any difficulties with the support of the teacher and colleagues.

RESULTS AND DISCUSSION

The analysis of the collected data revealed a positive impact on student learning, highlighting the effectiveness of using PhET Colorado in teaching electrical circuits. The direct manipulation of variables in simulation environments favors a deeper understanding of the theoretical concepts of electricity. Virtual and augmented simulations, especially when integrated into active and student-centered learning approaches, have been shown to be effective tools for improving conceptual understanding and student engagement. These tools can effectively replace traditional laboratories, providing a viable and efficient alternative for teaching electrical circuits (Başer and Durmuş, 2010; Álvarez-Marín et al., 2021; Bantolo and Mistades, 2021.).

The questionnaires applied before and after the activities showed a significant advance in the assimilation of the contents by the students. Unlike the traditional theoretical approach, PhET allowed students to visualize and experience the effects of their actions, favoring active learning that is connected to the reality of physical phenomena.

This hands-on experience allowed students to internalize complex knowledge, such as the relationships expressed by Ohm's Law, more intuitively.

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The development of cognitive skills was also evident in the observations made during the use of the simulator. The students were encouraged to formulate hypotheses, test configurations and analyze the results of their actions. By exploring series and parallel circuits, for example, students were encouraged to reason about how the arrangement of resistors affects total resistance and electric current.

Simulators are valuable tools in the development of cognitive skills, allowing students to formulate hypotheses, test configurations, and analyze the results of their actions. Proper modulation of task complexity and integration of simulations with traditional practices are crucial to maximizing educational benefits. While simulators significantly improve cognitive abilities, their impact on students' confidence can vary (Abbasy, 2012; Secomb et al., 2012).

This process promoted the exercise of logical reasoning and problem solving, as students needed to identify patterns and relate theoretical concepts to the behaviors observed in the simulated circuits. According to Wieman et al. (2008), the practice in interactive simulations facilitates the development of these skills, as it allows for controlled and visual experimentation.

Interactive simulations are powerful tools for skill development because they allow for controlled and visual experimentation, which facilitates learning and retention of complex skills. Studies show that these simulations significantly improve performance in diverse contexts, highlighting their relevance and effectiveness as methods of teaching physics (Wieman et al., 2008; Ceberio et al., 2016; Candido et al., 2022; Ogegbo and Ramnarain, 2022).

The ability to synthesize was another improved cognitive skill, especially in activities that required the integration of acquired knowledge. At the end of the activities, the students were encouraged to report their conclusions and describe how the variables were related within the electrical circuits. This synthesis exercise promoted a critical review of what was learned, facilitating the consolidation of the concepts worked on (Jones et al., 1963; Kopplin et al., 1963).

In addition, the task of organizing and explaining ideas also contributed to the development of scientific communication among students, who needed to present their interpretations in a clear and objective manner, which strengthened their capacity for scientific argumentation (Coelho, 2002).

PhET Colorado also played an important role in strengthening the students' role in the learning process. The interactive nature of the simulations allowed students to take

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control of their actions, making decisions about how to configure the circuits and what variables to exploit (Perkins et al., 2006; Wieman et al., 2008; Moore et al., 2013).

This protagonism was essential for the engagement of the students, because by becoming agents of their own discoveries, they showed greater motivation and interest in the content. According to Wieman (2007), the use of simulations encourages the active participation of students, promoting a more engaging and personalized learning, since each student can explore the content at their own pace (Wieman, 2007).

It was observed that the engagement of students in activities with PhET Colorado was higher than that recorded in conventional lectures. During the simulation activities, the students were curious and willing to test different combinations and hypotheses, which favored a dynamic learning environment. This increase in engagement is particularly important for physics education, a discipline that often faces challenges in maintaining student interest (Wieman et L., 2008; Petrova, 2020; Najib et al., 2022).

By allowing students to experience the concepts of electrical circuits in practice, PhET Colorado contributed to making learning more attractive and accessible, overcoming the limitations of traditional approaches based on the transmission of knowledge (Bezerra et al., 2011).

Social interaction also played a relevant role in the activities, since the students often discussed among themselves the best ways to configure the circuits and solve the proposed problems. This collaborative aspect reinforces Vygotsky's (1991, 2000, 2002) socio-interactionist theory, which values learning through social and cultural interaction.

During the activities, the students exchanged ideas and corrected each other, promoting collective learning where each participant contributed with their perspective. This interaction was essential for the development of cooperation and communication skills, which are increasingly valued in contemporary education. Interaction between students during educational activities, where they exchange ideas and correct each other, is essential for the development of cooperation and communication skills.

Cooperative learning not only improves these skills, but also increases motivation, engagement, and fosters positive interpersonal relationships. These benefits are observed at all levels of education and in various disciplines, making cooperative learning a valuable pedagogical approach in contemporary education (Bossert, 1988; Gillies, 2016).

Finally, the overall impact of using PhET Colorado in the teaching of electrical circuits highlights the importance of integrating technology and active methodologies into the educational process. The simulator not only facilitated the understanding of the concepts, but also encouraged the development of an investigative posture in the students, promoting a complete learning experience. The integration of technology and active methodologies, such as PhET, is essential for a more complete and effective learning experience (Vick, 2010; Fuada et al., 2023).

By allowing students to test their hypotheses and visualize electrical phenomena in real time, these simulations promote more engaged, motivating, and effective learning. Students who utilize PhET demonstrate a better conceptual understanding, higher academic performance, and an improved ability to apply theoretical knowledge in practical situations. (Wieman, 2007; Vick, 2010; Anisa and Astriani, 2022; Mahyuny et al., 2022).

The results suggest that the use of interactive simulations such as those at PhET Colorado is a viable solution to improve physics teaching in environments with limited infrastructure. These tools not only meet the pedagogical needs of an education focused on student protagonism and interaction, but also increase engagement, improve academic performance, and develop essential competencies. The flexibility of using PhET simulations in different educational contexts further reinforces their applicability and effectiveness (Perkins et al., 2006; Wieman et al., 2008; Sotiriou et al., 2010).

The methodology employed with PhET Colorado stands out as an effective practice to promote understanding, engagement, and the development of cognitive skills. PhET's interactive simulations not only improve learning outcomes and problem-solving, but also increase student motivation and engagement. In addition, they facilitate a deeper understanding of scientific concepts and promote the development of cognitive and scientific skills, preparing students to face future academic and scientific challenges (Wieman et al., 2008; Mahyuny et al., 2022; Rayan et al., 2023).

CONCLUSION

The analysis of the results obtained with the use of PhET Colorado in the teaching of electrical circuits demonstrated that the simulator is a viable and effective tool for learning complex concepts in physics. The use of simulations allowed students to experiment in a practical and controlled way with theoretical concepts, such as voltage, current and resistance, promoting a deeper and more intuitive understanding of the content (Vick, 2010; Masruroh et al., 2020; Fuada et al., 2023).

The interactive experience offered by PhET allowed students to visualize electrical phenomena and manipulate variables, facilitating the assimilation of knowledge that, in traditional approaches, could be considered abstract and distant (Gomes et al., 2020). Thus, PhET Colorado stood out as a resource that combines theory and practice, contributing to a more complete learning that is connected to the students' reality.

Among the main contributions of this study to the teaching of physics, the encouragement of students' protagonism and autonomy stands out. The simulation allowed students to explore electrical circuits independently, building and testing their hypotheses. This process promoted a greater engagement with the discipline, since the students were able to act as agents of their own learning, instead of just receivers of information).

According to Wieman (2007), methodologies that encourage experimentation and decision-making tend to foster deeper and more lasting learning, which reinforces the value of PhET as a pedagogical tool that stimulates critical thinking and problem solving.

The use of PhET Colorado has also contributed to an inclusive and adaptable teaching approach, since the simulator is accessible to all students and does not require a complex physical infrastructure. In schools where physics laboratories are limited or non-existent, PhET represents a practical alternative to provide an experiential learning experience, essential for understanding physical phenomena (Doz, 2020; Petrova, 2020; Wirda et al., 2023).

This accessibility is particularly relevant in the Brazilian educational context, where infrastructure disparities between schools are common (Bezerra et al., 2011). In this way, PhET Colorado can act as a tool for democratizing physics education, expanding access to quality education.

To enhance the use of PhET Colorado and further enrich the teaching of electrical circuits, future studies could explore the integration of the simulator with other active methodologies, such as problem-based learning and teamwork. These strategies could enhance the effectiveness of PhET by fostering a collaborative environment, where students not only experiment individually, but also discuss and exchange knowledge with each other, strengthening collective learning (Rahmadita et al., 2021; Mahyuny et al., 2022; Widiarta et al., 2023).

In addition, investigating the impact of the use of PhET in other areas of physics, such as mechanics and thermodynamics, can expand the possibilities of application of the simulator, making it an even more versatile resource in science teaching (Coelho, 2002).

In summary, the use of PhET Colorado in the teaching of electrical circuits shows promise, offering an effective alternative to overcome the limitations of traditional approaches and promote practical and interactive learning.

The experience accumulated in this study shows that PhET is more than a simple technological tool; it represents a change in the way physics is taught, where students are encouraged to explore, question, and build their own knowledge (Perkins et al., 2006; Ganasen and Shamuganathan, 2017; Najib et al., 2022; Pranata, 2023; Wirda et al., 2023).

The continuity of research on the use of simulators such as PhET in physics teaching can contribute to the development of pedagogical methodologies that are increasingly adapted to the needs and the current context, consolidating a more engaging and accessible science education.

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