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# COMPUTATIONAL SIMULATIONS IN PHYSICS TEACHING: CHALLENGES AND POTENTIALITIES

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## ABSTRACT
The study aimed to analyze the impact of computer simulations on science teaching, with emphasis on PhET simulations, evaluating their effectiveness in learning and student motivation. The research addressed the use of simulators as a pedagogical tool to assist in the understanding of abstract concepts, promoting active learning and encouraging student engagement. A bibliographic approach was adopted, based on the review of scientific articles, academic books and publications indexed in databases, such as Google Scholar. The methodology consisted of identifying the theme, selecting and critically analyzing the materials and organizing the references to support the discussion. The results showed that computer simulations facilitated the assimilation of scientific content, providing interactive experiences that made the concepts more accessible to students. In addition, it was found that the use of these tools in face-to-face and distance learning favored the autonomy of students and enabled the replacement or complementation of laboratory experiments. However, some challenges were identified, such as the need for teacher training for the proper use of simulations and the limitation of some modeling in the faithful representation of physical phenomena. It was concluded that computer simulations constitute an innovative resource for science education, requiring methodological adaptations to maximize their benefits. Thus, it was recommended to expand research on the integration of these technologies in different educational contexts.

**Keywords:** Simulations. PhET. Teaching. Sciences. Technologies.

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## INTRODUCTION

The incorporation of digital technologies in science teaching has proven to be a viable alternative to face challenges related to the abstraction of content and the lack of interest of students. The need for innovative methodologies that promote active and interactive learning becomes evident, especially in view of the difficulties that students encounter in understanding complex scientific phenomena. The use of computer simulators, such as *PhET* simulations, emerges as an effective pedagogical resource, allowing the visualization and experimentation of concepts that would otherwise be inaccessible in traditional teaching environments. In addition, simulations allow teachers greater autonomy and offer support for face-to-face and distance courses, ensuring the continuity of learning even in the absence of physical laboratories.

Given the relevance of the theme, the research has the general objective of analyzing the impact of computer simulations on science teaching, with emphasis on *PhET* simulations, evaluating their effectiveness in learning scientific concepts and in motivating students. To achieve this purpose, three specific objectives are established: (1) to verify whether *PhET* simulations contribute to the understanding of abstract concepts in the teaching of Physics; (2) identify the role of these tools in increasing student engagement and promoting active learning; and (3) examine the main limitations and challenges of implementing these technologies in different educational contexts. In view of this panorama, the following question arises: 'do computer simulations, especially *PhET* simulations, represent an efficient alternative to improve science teaching, favoring student learning and motivation?'

To answer this question, the research is developed through a bibliographic review, based on the approach proposed by Narciso and Santana (2024), who discuss scientific methodologies in education and propose new paths for research in the area. The data analysis follows a qualitative approach, based on the selection and interpretation of studies that discuss the impact of computer simulations on science education. The data are collected from scientific articles, books and academic reports that address the use of these tools in the teaching of Physics and Science.

The structure of the article is organized into interlinked sections. Initially, the article presents the theoretical foundation, addressing aspects such as the use of simulators in the teaching of Science, their potentialities and impacts on learning, as well as the challenges in the implementation of computer simulations in the teaching of Physics. Next, the Results and Discussions section analyzes the main findings of the research, relating them to previous studies and discussing their implications. Finally, in the Final Considerations, the investigated questions are resumed, highlighting the main conclusions, limitations and suggestions for future research.

Therefore, the investigation contributes to the debate on the use of computer simulations in science teaching, evidencing its potential as a didactic tool and pointing out challenges that must be overcome to maximize its effectiveness in student learning.

## METHODOLOGY

The research was conducted through a bibliographic approach, which, according to Santana, Narciso and Santana (2025), consists of the survey, selection and critical analysis of academic materials relevant to the research problem. This type of methodology allowed us to gather and organize knowledge already consolidated in the literature on the use of computer simulations in science teaching, enabling the understanding of its potentialities and challenges. The research was based on the collection of data from various sources, including scientific articles, academic books and theses, as well as specialized journals in the area of science education and teaching.

In this context, the methodology consisted of the identification of the theme and the formulation of the research question, followed by the systematic search of relevant materials in academic databases. The process involved consulting *Google* Scholar, a search platform developed by *Google* that indexes scientific literature from a variety of sources, including peer-reviewed journals, theses, books, and conferences. This tool has made it possible to access a wide variety of studies on the impact of computer simulations on science education. In addition, journals available in digital libraries and academic repositories were used, ensuring a comprehensive and up-to-date bibliographic survey.

The keywords used to search for the materials were selected with the objective of covering different aspects of the investigated theme. To this end, simple combinations such as 'computer simulations', 'science teaching', 'active learning', '*PhET* and Physics' and 'use of technology in education' were used. These expressions were searched in isolation and in different combinations to ensure the comprehensiveness of the review.

The methodological process followed some fundamental steps. Initially, the inclusion and exclusion criteria for the analyzed materials were defined, prioritizing studies published in recent years and that were relevant to the topic addressed. Next, the selection of sources was carried out, considering peer-reviewed articles, book chapters, and recognized research in the area. Subsequently, the critical analysis of the materials allowed the comparison between different theoretical perspectives, enabling a dialogue between the authors and the contextualization of the findings within the scope of the research. Finally, the references were organized in a systematic way to support the discussion and the results obtained throughout the study.

In this way, the methodology adopted enabled a detailed survey of the evidence available in the literature, allowing to answer the research question and critically analyze the impact of computer simulations on science teaching. The use of a bibliographic approach ensured a broad understanding of the subject, evidencing the benefits and limitations of these technological tools in education.

## USE OF SIMULATORS IN SCIENCE TEACHING: POTENTIALITIES AND IMPACTS ON LEARNING

Science education faces constant challenges, especially with regard to the lack of interest of elementary school students. As pointed out by Ferreira, Pereira and Sousa (2019, p. 33), "we noticed that in the school environment there is a wear and tear regarding the interest of elementary school students with regard to the subject of science." This phenomenon can be attributed to the lack of dynamic and interactive methodologies that bring the content closer to the students' reality. Thus, it is essential to search for innovative strategies that stimulate learning and promote greater student engagement.

In this context, the use of simulators emerges as a promising pedagogical alternative, since it enables the creation of a realistic environment in which the student is challenged to make decisions and perform actions, favoring active learning and the construction of knowledge. According to Ferreira, Pereira and Sousa (2019, p. 32), "the advantage of simulation is that it creates a realistic environment where the student is presented with a problem so that he can make decisions and perform actions." In this way, science teaching ceases to be a passive transmission of content and starts to incorporate practices that encourage experimentation and problem solving, approaching the principles of learning by discovery.

In addition, the implementation of simulators in the school environment not only improves the understanding of scientific concepts, but also develops the student's investigative sense. As highlighted by Ferreira, Pereira and Sousa (2019, p. 31), "simulators provide a better interpretation of certain experiments in addition to motivating students in their sense of research, making them start to stick to this practice of research and how things work." Thus, when interacting with the simulation, the student not only visualizes processes that would often be unfeasible in the school environment, but also actively appropriates the knowledge.

In addition, the introduction of simulators in teaching is in line with the technological transformations of contemporary society, which directly influence the way students learn and interact with knowledge. As Ferreira, Pereira and Sousa (2019, p. 33) point out, "simulators end up motivating students, as we are in a technological era where any way of passing on content using this medium ends up attracting attention." In this way, by incorporating simulators in science teaching, the teacher establishes a closer connection with the students' reality, making learning more dynamic and attractive.

In view of this, it is verified that the use of simulators represents an effective alternative to overcome the difficulties faced in science teaching, contributing to the motivation of students and to the construction of meaningful learning. Therefore, the adoption of these technological resources not only expands the methodological repertoire of the teacher, but also favors the formation of more critical and autonomous students, capable of understanding and applying scientific concepts in a contextualized and interactive way.

## CHALLENGES IN THE USE OF COMPUTER SIMULATIONS IN PHYSICS TEACHING

The use of computer simulations in the teaching of Physics has been widely discussed in the literature as a tool capable of expanding the understanding of scientific phenomena. However, despite its advantages, its implementation in the classroom presents significant challenges that must be considered for teaching-learning to be effective. According to Jaime and Leonel (2024, p.4), "computer simulations bring several new challenges in the classroom", which demonstrates the need for a careful approach by educators in the selection and application of these tools.

Thus, although simulations are recognized as valuable resources for teaching, they do not guarantee, by themselves, success in the learning process. As pointed out by Jaime and Leonel (2024, p.3), "it is important to note that, although computer simulations are an asset in the teaching-learning process of Physics, they are not a guarantee of total success". This statement highlights that, although they allow a better visualization of abstract concepts and favor an interactive environment, their inappropriate use can compromise learning. Thus, it is essential that educators are prepared to use these tools effectively, considering their limitations and applicability within the pedagogical context.

In addition, it should be considered that the complexity of some simulations can represent a barrier for students. According to Jaime and Leonel (2024, p.3), "one of the main challenges is that simulations can be complex and difficult to use, which can make it difficult for students to understand the topic to be addressed". This means that, even if simulations allow the exploration of different scenarios and the manipulation of variables, their effectiveness can be reduced if students do not have the necessary prior knowledge to correctly interpret the results presented. In this way, the teacher's mediation becomes indispensable to ensure that the experience with simulations effectively contributes to the construction of knowledge.

On the other hand, a determining factor in the effectiveness of simulations is the modeling of the physical system represented. As stated by Jaime and Leonel (2024, p.3), "depending on the modeling of the physical system to be represented, the simulation becomes more or less 'realistic'". This point reveals that simulations rely on mathematical models and simplifications of reality, which can limit the accuracy and fidelity of the phenomena portrayed. Therefore, it is essential that educators clarify to students the approaches adopted and the limits of the models used, avoiding the creation of misconceptions about the physical phenomena studied.

In view of these considerations, it is concluded that, although computer simulations represent a significant advance in the teaching of Physics, their implementation requires planning and adequate teacher training. Thus, it is essential that teachers understand the challenges inherent to this resource and develop strategies to minimize its limitations. Only in this way will it be possible to enhance the benefits of simulations and ensure that they are used as effective tools in the construction of scientific knowledge.

## PHET SIMULATIONS AND THEIR CONTRIBUTION TO THE TEACHING OF PHYSICS

Since the creation of *PhET Interactive Simulations*, in 2002, this platform has provided teachers with considerable autonomy in the choice of didactic strategies for the application of simulations in the classroom. According to Medeiros Jr, Naia and Lopes (2024, p. 2), "a lot of autonomy was granted to teachers with regard to the ways in which simulations were used". This demonstrates that, over the last decades, there has been a flexibility in the use of these tools, allowing adaptations according to the specificities of the teaching of Physics in different educational contexts.

In addition to the autonomy granted to teachers, *PhET* simulations stand out for their ability to facilitate active learning and the understanding of abstract concepts. According to Medeiros Jr, Naia and Lopes (2024, p. 3), "*PhET* simulations are interactive tools that facilitate active learning and the understanding of abstract concepts, making visual phenomena that, in practice, would be invisible". In this way, the visual representations provided by these tools allow students to explore complex content in a more accessible way, which can contribute to a more effective assimilation of physical concepts.

In this sense, it is evident that *PhET* simulations not only improve the educational experience in face-to-face environments, but also play a relevant role in Distance Education (DE). As pointed out by Medeiros Jr, Naia and Lopes (2024, p. 8), "in distance education undergraduate courses, *PhET* simulations can replace or complement laboratory experiments that would be difficult to perform remotely". Thus, given the limitations inherent to remote experimental teaching, these simulations represent a viable alternative for maintaining the quality of practical learning, ensuring that students can carry out experiments even at a distance.

In addition to the practical applications of *PhET simulations,* several studies have sought to analyze their effectiveness in the teaching of Physics. According to Medeiros Jr, Naia and Lopes (2024, p. 1), "the analyses took into account the effectiveness of PhET simulations in learning Physics, through the collection of data regarding sample size, mean and standard deviation". In this way, the impacts of these tools were measured through rigorous statistical approaches, allowing an objective evaluation of their pedagogical benefits.

From these investigations, it was found that *PhET simulations* demonstrate equivalent or superior performance compared to traditional teaching methods. According to Medeiros Jr, Naia and Lopes (2024, p. 1),

> [...] the effectiveness of *PhET* simulations in the learning of Physics was duly proven, revealing superiority, or at least equivalence, when compared to the use of conventional laboratories and traditional teaching methods.

Thus, it is evident that the use of these tools can be an effective solution both in face-to-face contexts and in distance learning modalities, ensuring that students have access to meaningful and interactive learning.

Therefore, it is observed that *PhET simulations* play a fundamental role in the modernization of Physics teaching, enabling greater teacher autonomy, promoting active learning and serving as an indispensable resource for face-to-face and distance education courses. If, on the one hand, these tools facilitate the visualization and understanding of abstract phenomena, on the other hand, empirical studies prove their effectiveness compared to traditional methods. In view of this, the need to expand the use of these technologies in teaching becomes evident, further exploring their potential in the construction of scientific knowledge.

## RESULTS AND DISCUSSIONS

The findings of this study confirm the relevance of computer simulations in science teaching, especially in the field of physics, reinforcing their ability to enhance learning and increase student engagement. As highlighted by Medeiros Jr, Naia and Lopes (2024, p. 1), the effectiveness of *PhET* simulations has been proven, demonstrating equivalence or superiority over traditional teaching methods, including conventional laboratories. This result converges with the observations of Ferreira, Pereira and Sousa (2019, p. 33), who identified a decline in students' interest in science teaching at the elementary level, a problem that can be mitigated by more dynamic pedagogical approaches, such as the use of simulators.

The positive impact of *PhET* simulations manifests itself in the form of active and interactive learning, providing a better understanding of abstract concepts. According to Medeiros Jr, Naia and Lopes (2024, p. 3), simulations make visible phenomena that, in practice, would be invisible, facilitating the construction of scientific knowledge. This characteristic corroborates the notes of Ferreira, Pereira and Sousa (2019, p. 32), who highlight the potential of simulators to create realistic environments that challenge students to make decisions and solve problems, promoting a more engaging learning experience.

Furthermore, the findings of this study confirm the applicability of *PhET* simulations in distance learning. According to Medeiros Jr, Naia and Lopes (2024, p. 8), these resources can replace or complement laboratory experiments in distance education courses, ensuring that students have access to experimental practices even in remote environments. This finding reinforces what Jaime and Leonel (2024, p. 3) argue about the need for effective teacher mediation in the use of simulations, especially when their implementation occurs in a digital context, where the absence of face-to-face supervision can compromise the learning experience.

However, despite the advantages evidenced, some limitations must be considered. The literature points out that the complexity of certain simulations can make it difficult for students to use them. Jaime and Leonel (2024, p. 3) warn that, depending on the modeling of the physical system represented, the simulation can become excessively abstract or unrealistic, which compromises students' understanding. In addition, these authors highlight that the success of the use of simulations is not guaranteed only by the tool itself, but depends directly on the way it is inserted in the educational process. Without qualified teacher mediation, students may encounter difficulties in interpreting the results or applying the concepts covered in the simulations.

In addition, some unexpected observations emerged during the analysis of the results. In some cases, it was found that students with less technological familiarity showed greater resistance to the use of simulations, presenting difficulties in interacting with digital interfaces. This finding is in line with Ferreira, Pereira and Sousa (2019, p. 31), who highlight that, despite the motivational potential of simulators, their effectiveness depends on the level of digital literacy of the students and the clarity in the presentation of the virtual experiments. Thus, it is essential to develop pedagogical strategies that minimize these barriers, ensuring that the introduction of these tools favors the inclusion of all student profiles.

Finally, the results of this study point to the need for future research that deepens the understanding of the effectiveness of *PhET* simulations in different areas of science education. It is recommended to conduct research that comparatively evaluates the impact of simulations in face-to-face and remote contexts, as well as their integration with other methodologies, such as project-based learning and gamification. In addition, future investigations can explore the development of more accessible and intuitive simulations, reducing the complexity of interfaces and making the use of these tools even more efficient for different audiences. In this way, it will be possible to improve the use of computer simulations in teaching, consolidating its role as an innovative and effective didactic resource.

## CONCLUSION

The present study allowed us to answer the questions raised in the introduction and in the methodology, demonstrating the relevance of computer simulations in the teaching of Physics and Science. Research has shown that these tools contribute significantly to learning, making abstract concepts more understandable and promoting greater student engagement. In addition, it was possible to verify that the use of *PhET* simulations, when well structured and integrated with pedagogical planning, can replace or complement laboratory experiments, especially in distance courses. Thus, the hypothesis that such resources offer an effective methodological alternative to face educational challenges related to the lack of practical experimentation and the lack of interest of students was confirmed.

The objectives of the research were fully achieved, as it was possible to analyze the effectiveness of *PhET* simulations in learning and understand their impact on the motivation and development of students' critical thinking. As highlighted throughout the study, the interactivity provided by these tools expands students' ability to visualize complex physical phenomena, allowing for more dynamic learning. In addition, it was found that, although the simulations have numerous advantages, their effectiveness is directly related to the way they are inserted in the educational context, reinforcing the need for qualified teacher mediation. Likewise, it was observed that challenges such as the technological familiarity of students and the complexity of some modeling still need to be faced to ensure the full use of these technologies.

In view of the findings, the research points out ways for future studies that can deepen the understanding of the applicability of simulations in science teaching. It is recommended that investigations be carried out that comparatively analyze the effectiveness of these tools in different age groups and educational contexts, considering both face-to-face teaching and Distance Education. In addition, it would be pertinent to explore the development of more accessible and intuitive simulations, in order to reduce technological barriers and make their use more inclusive. Thus, it is expected that future research can contribute to the improvement of methodologies based on computer simulations, consolidating them as fundamental strategies for the teaching of Science and for the formation of more critical and autonomous students.

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