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Science Education Based On Interactive Computer Simulations

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Abstract:
The lack of science laboratories, basic equipment, and didactic materials in many public schools makes it difficult to carry out hands-on experiments, which are essential for learning science. The purpose of this article is to present a proposal for the use of interactive computer simulation to facilitate the teaching of science in 9th grade classrooms. An exploratory, qualitative study was conducted with 128 students from a public school in the municipality of Fortaleza, in the state of Ceará, Brazil. The methodological path was implemented in four pedagogical stages: a) didactic contract and information about the tool; b) interaction with the tool; c) conflict situation; and d) new interaction with the tool. The results showed that the use of interactive computer simulations developed by the PhET platform, together with an appropriate teaching methodology, provided a practical, interactive, and inclusive approach to the students' learning process. This pedagogical strategy proved to be effective in promoting student engagement, motivation, and preparation. In addition, students were found to be better prepared to understand and explore related scientific concepts in greater depth.
Key Words*: Computer simulation; Science teaching; PhET; Interactive simulations; Digital technologies.*

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I. Introduction

Science education in the final years of elementary school is a fundamental pillar in the comprehensive education of students, promoting the development of complex and strategic cognitive skills such as critical analysis, problem-solving, and evidence-based decision-making (Nascimento et al., 2010). By providing an in-depth understanding of natural phenomena and the interaction between humans and the environment, this area of knowledge contributes to the development of a scientific worldview that fosters attitudes of active and responsible citizenship, with a special emphasis on the preservation of the planet.

The challenges for science education in Brazil are significant, especially in the public school system. In general, school infrastructure is precarious, didactic resources are limited, the training of professors is inadequate (Silva et al., 2017), the curriculum is outdated, and there are large social inequalities that affect access to quality education. In addition, the workload allocated to science teaching is insufficient (on average, two hours per week), students lack interest in the content, and classes are often expository and consist of repetitive exercises, among other problems (Moreira, 2021).

Many public schools do not have adequate and/or available science laboratories, basic equipment, or sufficient didactic materials (Gonçalves et al., 2020). This limitation makes it even more difficult to carry out hands-on experiments, which are essential for learning science. In addition, the lack of up-to-date teaching resources, such as books and interactive materials, also limits the possibilities for more dynamic and interesting teaching for students. Science should be presented in a way that attracts students' interest (Santos & Menezes, 2020). According to Moreira (2021), for students to be interested, the content must make sense to them (Moreira, 2021). Interest in learning, also known as predisposition to learn, is one of the necessary conditions for meaningful learning (Ausubel, 1968; Moreira, 2012; Silva, 2020). In addition, this will not happen if the situations do not make sense to the students.

In addition to what was said in the previous paragraph, poor working conditions, unprepared professors, and an outdated science curriculum make learning this subject even worse. Although we are in the 21st century, with its socio-cultural changes driven by digital information and communication technologies (DICT), science education is still based on 19th century concepts (Moreira, 2017; Cavalcante et al., 2018). Moreover, the initial training of science professors is often inadequate for the reality of most schools. The way science is taught at the undergraduate level in most research universities is not only ineffective, but also does not follow scientific principles (Wieman, 2013).

In Brazil, the science teacher in the last years of elementary school is trained in three different areas: biology, physics or chemistry. Although they have specific training in one of these three areas, science professors in the final years of elementary school have to teach content from all areas (biology, chemistry, and physics). This requires professors to be constantly updated and prepared to teach subjects that may not have been the focus of their training. Moreover, this is another challenge, namely the professional training of professors with a focus on specific content and not just general content (Wilson, 2013). Professors who are trained in one specific area may not have the same depth of knowledge in other areas. For example, a biology professor may find it difficult to approach physics or chemistry content with the same confidence. In this way, the quality of teaching can vary depending on whether the professor has more or less affinity with the content. Consequently, depending on the professor's training, students may receive a more robust or a more superficial science education.

The diversity of the science professor's training can be a disadvantage in schools with limited educational resources, where it is difficult to provide adequate materials and equipment for all areas of science. The lack of physical structure of the school makes it impossible to experiment with all the students, limiting the class to theory only, which limits the teaching-learning process (Santos & Menezes, 2020), especially in chemistry classes. For example, the study of atomic structure is a topic that often poses significant challenges for students due to its high level of complexity and the need for considerable abstraction skills.

Considering this gap of limited resources for experimentation in chemistry education, digital technologies, such as computer simulators, can play an important role by making it possible to carry out virtual experiments that would be impractical or impossible to carry out in real physical laboratories due to resource, safety and/or time limitations. It should be noted that these resources are methodological alternatives to enrich the pedagogical practices of professors (Diógenes et al., 2023).

Based on the justifications presented, the aim of this article is to present a proposal to use computer simulation to facilitate the teaching of science in 9th grade classes, linked to a teaching methodology. The PhET colorado platform, a free, easy-to-use tool, was used to implement interactive computer simulation in the classroom. PhET (Physics Education Technology) Colorado is a project of the University of Colorado that develops interactive simulations of science and mathematics.

This research is divided into sections. Section 1 presents the research problem and objectives. Section 2 deals with the theoretical basis of the research, listing the principles that guide the use of the computer simulation available on PhET (phet.colorado.edu). Section 3 describes the methodological steps in using the simulations/interactions with 9th grade students. Section 4 then presents the results of the research and a brief analysis of the students' interactions. Finally, in Section 5, we express our concluding thoughts.

II. Phet: Interactive Computer Simulations

To use computer simulations in the classroom, we use PhET Simulations (phet.colorado.edu). With access to the Internet, the professor can use the simulations available on the site at various times during the class. The interactive simulations are divided into five knowledge areas: Physics, Chemistry, Biology, Earth Science, and Mathematics. Figure 1 shows the interface of the platform.

When accessing the chemistry section, the student can choose the simulator, such as the "Build an Atom" simulator. The advantage of PhET is that students can either access it online or download the simulator to study offline. The online version provides the main topics covered in the simulation and the learning objectives. In addition, teaching resources and guided activities are made available to students (Figure 2). In this case, however, it is necessary for the professor to register on the platform.

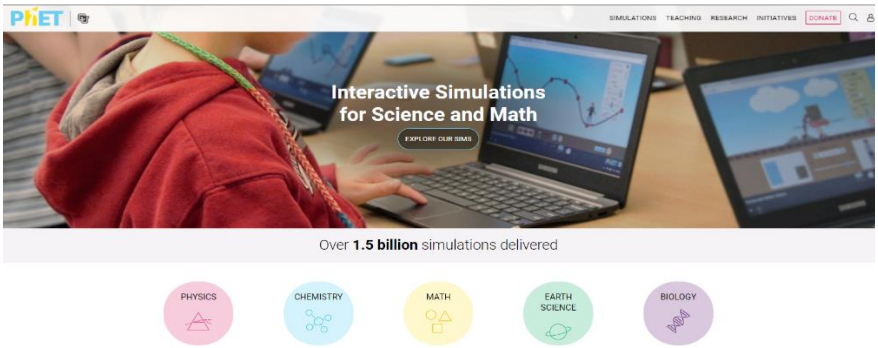

Figure 1 - PhET website interface

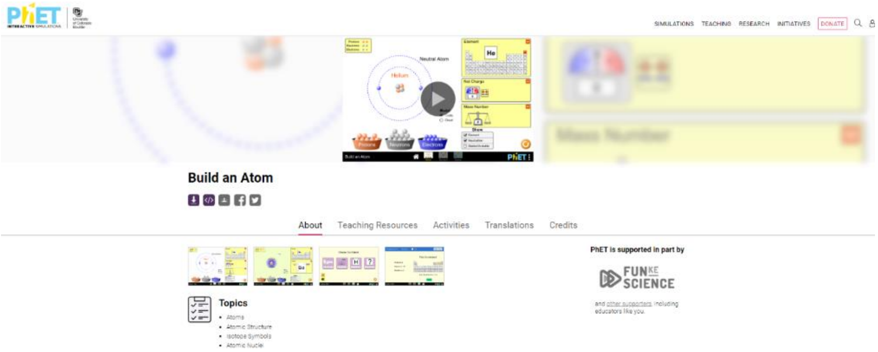

Figure 2 - PhET interactive computer simulation interface

The Build an Atom simulation has three initial interfaces. The first allows students to build an atom using spheres representing subatomic particles (protons, neutrons, and electrons). When the student accesses the simulation, they have the option of assembling an atom in the way they prefer, so the student works on interactivity (support for mental realizations and actions), autonomy (initiative and decision-making), cooperation (exchange of ideas and collective work on the presented concept), cognition (cognitive overload on the learner's memory), and affectivity (feelings and motivations) (Diógenes et al., 2023).

III. Material And Methods

Setting and Participants

The teaching methodology was developed during science classes in the second semester of 2023 with 128 students from four 9th grade classes in a public school in the municipality of Fortaleza/Ceará. Based on the Brazilian National Common Core Curriculum (BNCC), the lessons aimed to promote the development of the ability to "identify models that describe the structure of matter (constitution of the atom and composition of simple molecules) and recognize their historical evolution" (EF09CI03). For this purpose, the "Build an Atom" computer simulation was used, which is available on the PhET Colorado website (https://phet.colorado.edu/en/simulations/build-an-atom).

Research Design

This is an exploratory study with qualitative data. Based on the model of Costa et al. (2020), the teaching methodology was implemented in four pedagogical stages: a) didactic contract and tool information; b) interaction with the tool; c) conflicting teaching situation used as an example; and d) new interaction with the tool.

Stage 1 - Didactic contract and tool information

In this stage, the relevance of using interactive technological materials contextualized with the student's reality as a tool for enriching learning was highlighted. In this context, the objectives and resources of the tool were presented, including the problem situation that served as a basis for the proposed activity. In addition, some basic features of the PhET tool were explained to the students, with instructions on how to use it and other resources. However, not all the features were revealed so that the students could discover them on their own.

Stage 2 - Interaction with the tool

This stage was dedicated to the student-computer interaction with the computer simulation. The aim was to allow the student to interact, question and discover some curiosities about the assembly of the atom. The emphasis on hands-on experimentation is a central element of the lesson, recognizing that learning can be more meaningful when students are interested in the lesson, manipulating and interacting with the tool used in the teaching process.

Stage 3 - Modeling a Conflicting Teaching Situation

In this stage, the activities and conflict situations on the theory of atomic structure were distributed. The aim of these activities was not to assess the students' knowledge of the chemistry content, but to explore how the students faced and resolved conflicts, or how they interacted with their peers (student-student interaction).

Stage 4 - New interaction with the tool

The professor suggested that each student build different configurations of atoms by varying the number of protons, electrons and neutrons. The reason for this was that the different configurations would promote a more robust understanding of atomic structure. In addition, the purpose of the different configurations is to explore aspects such as atomic instability and the resulting charge.

IV. Results And Discussion

For the results of the research, it is important to note that the aim was to familiarize the students with the computer simulation and not to assess their understanding of the atomic structure concepts covered during the implementation. Figure 3 shows an example of an atom built by one of the students, who chose the boron atom with five protons, three neutrons and six electrons.

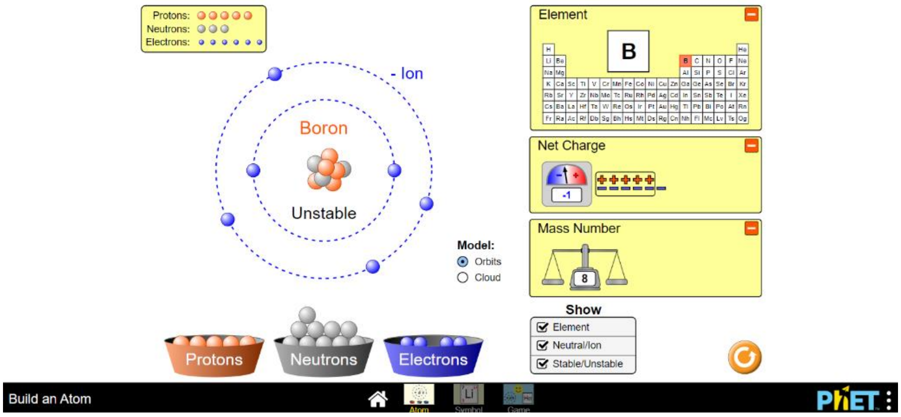

Figure 3 - Boron atom built by the students using the PhET simulation

The atom was developed by the student in a free-form manner, as requested by the professor of the subject. This activity corresponds to the second stage of the teaching methodology (interaction with the tool). The students found it easy to use the tool to build a random atom with different numbers of protons, neutrons, and electrons. Figure 4 shows the students' interaction with the tool.

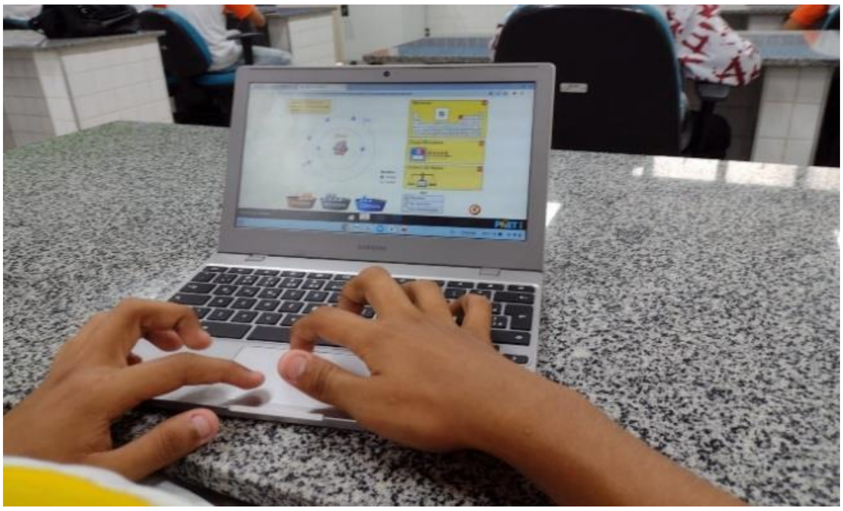

Figure 4 - Student interactions with the PhET simulation during the lesson

The students' interaction with the tool was important for them to understand how the PhET simulator works. We also highlight the students' participation with their peers (student-student), which allowed cooperative learning and understanding the details of a methodological path for using PhET as a digital teaching resource.

In the third stage (conflict situation), the activities guided in class played a fundamental role in the learning process, allowing the development of essential skills such as autonomy, teamwork, and collaboration. At this point, students learned to communicate their ideas, share tasks, and work together to achieve a common goal. The activities were designed to promote a deeper and more meaningful understanding of scientific concepts.

In today's educational scenario, the importance of technological resources to support student teaching and learning is becoming increasingly evident. In this sense, Cavalcante, Sales and Silva (2018, p. 3) pointed out that "[...] it is interesting that this student is in an environment with professors who use not only resources such as the brush and the chart, but above all active methodologies and digital technologies".

The use of technological simulations has gained notoriety in the educational context as a didactic resource in teaching practices (Diógenes et al., 2023). PhET is a tool that has stood out for giving students the opportunity to interact with abstract chemical concepts in a visual and practical way. In the field of science education, computer simulation has proven to be particularly valuable in allowing students to explore and understand scientific phenomena more effectively.

The use of this simulation provided several benefits to the students. First, the simulation provided a concrete and interactive visualization of atomic structure, making the concepts more tangible and understandable. Students were able to experiment with assembling atoms, observe how varying the number of protons, neutrons, and electrons affects their properties, and understand the relationship between atomic configuration and their chemical properties.

Our observations are in line with the perspective of Santos and Menezes (2020), who point out that experimental activities are important for learning different types of knowledge (procedural and attitudinal) and not only conceptual knowledge. In addition, they contribute to developing the ability to work in groups, stimulate creativity, and improve the ability to observe and record information.

In the fourth stage (new interaction with the tool), by exploring different scenarios (atomic configurations) and understanding the consequences of their decisions, we see the development of the students' creativity, curiosity, and critical thinking. This moment is important because it makes it possible to set up experimental situations that would be impossible or dangerous in a proper environment. In the case of the "Build an Atom" simulation, students could experiment with combining different chemical elements safely, exploring the properties of unstable atoms. This provided a hands-on experience without the risks associated with real experiments.

We also found that the University of Colorado's PhET Interactive Simulations platform offered a wide variety of interactive simulations, giving the professor access to a diverse set of educational resources, allowing for more dynamic and engaging lesson planning. It also provided a more engaging and effective approach to student learning. Through direct interaction with scientific concepts, students were able to develop observation, analysis, and problem-solving skills.

Another positive aspect of using computer simulations is the flexibility they provide. Students were able to access the simulations both in the classroom and at home, allowing them to review and practice concepts independently. This contributes to the development of students' autonomy and encourages them to explore and deepen their scientific knowledge. As highlighted by Gonçalves, Silva, and Vilardi (2020), experimental activities promote student participation by encouraging them to play a leading role in the process of expanding and consolidating their knowledge.

Computer simulations in science education can stimulate students' interest in the subject and increase their engagement and motivation. By providing an interactive and fun experience, simulation stimulates students' curiosity and encourages them to investigate and seek answers to their own questions. This more dynamic and hands-on approach has the potential to contribute to the formation of a solid scientific knowledge base and the development of students' scientific thinking.

It is important to emphasize that computer simulation does not completely replace traditional experimental practices, but serves as a valuable complement. Simulations can be used as a first step to introduce complex concepts, allowing students to understand the basic principles before performing real experiments in the laboratory. In this way, simulation prepares students by providing them with a solid theoretical foundation and promoting a better understanding of the phenomena observed during experimental practice.

V. Conclusion

We observed that the computer simulation "Build an Atom", provided by the PhET platform, demonstrated the importance and benefits of computer simulations in science education at the 9th grade level. By providing a hands-on, interactive and inclusive approach, simulations contribute to educating students who are more engaged, motivated and prepared to understand and explore the scientific world around them. Considering the objective proposed at the beginning of this study, we highlight and confirm the fact that "the effective use of digital technologies in the classroom must always be underpinned by an appropriate and consistent teaching and learning methodology" (Cavalcante et al., 2018, p. 10).

The results obtained in this study suggest that the use of digital technologies in school for pedagogical purposes should be approached with active learning methodologies that put the student at the center. It should be noted that, despite the importance of technologies for education, their use alone, without planning, does not guarantee that student learning will be more meaningful (Moreira, 2021), but they do have the potential to stimulate student interest in learning curriculum content. Therefore, it is essential that science teachers be trained to effectively integrate these tools into the classroom to promote a dynamic and interactive classroom environment that fosters student engagement and autonomy. In addition, it is important to continually monitor and evaluate the impact of these technologies on learning, and to adjust approaches as necessary to maximize pedagogical benefits.

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