STEM EDUCATION THROUGH PHET MODELING: A CASE OF TEACHING ATOMIC PHYSICS

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ABSTRACT

The subject of physics, particularly the section on atomic physics, is a complex and significant field in explaining scientific foundations and intricate processes. To simplify such complexity and enhance students' understanding, the use of PhET interactive simulations is one of the effective solutions. This article explores the teaching of atomic physics topics within the STEM framework and the potential of PhET modeling. The central idea of this study is to determine the effectiveness of teaching atomic physics through the use of PhET modeling within the STEM education approach. This research aims to evaluate the effectiveness of using PhET simulations in teaching atomic physics through the STEM method. The study was conducted within the framework of pedagogical practice, during which simulations such as Rutherford Scattering, Hydrogen Atom, Blackbody Spectrum, and Fourier were used in the learning process. During the research, it was revealed that PhET models allow learners to be not just passive listeners, but active participants in the learning process.

Keywords: STEM education, PhET simulation, atomic physics, interactive learning, teaching methods.

INTRODUCTION

One of the major challenges in today's global education system is the declining interest of students in natural sciences and the difficulties they face in mastering exact sciences. Subjects such as physics, chemistry, and mathematics are often perceived as complex and intimidating by learners. The decreasing level of scientific literacy has become a pressing issue that poses a significant barrier at the global level.

In this context, the STEM education approach and PhET interactive simulations, widely used in international practice, can serve as effective tools for delivering high-quality and modern education in Kazakhstan as well. STEM is not merely an integration of the disciplines of Science, Technology, Engineering, and Mathematics, but also a system of education and professional training based on innovation, scientific inquiry, and technological problem-solving [1].

Lee and other researchers emphasize the importance of cognitive science and the thinking process in studying STEM education, describing it as a complex cognitive process that involves deep thinking, problem-solving, and active intellectual engagement [2].

Khairuddin and Bangkok demonstrate the effectiveness of combining the STEM approach with PhET simulations in fostering students' critical thinking skills and highlight how interactive modeling enhances learners' cognitive engagement [3].

In his study, Perkins comprehensively analyzes the role of PhET interactive simulations in transforming STEM education. He provides strong evidence that these tools modernize the learning process by making complex concepts in natural sciences more intuitive, visual, and technologically accessible [4].

Lestari, by integrating STEM and problem-based learning approaches, observes that PhET-based instructional materials significantly enhance students' understanding of core concepts and develop their ability to solve complex problems in physical and mathematical contexts [5].

The use of PhET simulations in physics lessons organized within a STEM framework has shown a positive impact on the development of higher-order thinking skills, underlining the role of visual modeling in promoting cognitive activity and analytical reasoning [6]. Applying PhET modeling in the context of STEM education stimulates students' cognitive engagement and helps reinforce theoretical knowledge through practical experience.

Although the integration of STEM education into physics teaching—particularly in atomic physics—is becoming increasingly relevant, research in this direction remains insufficient. There is a notable lack of methodological recommendations and evidence-based scientific studies on how to deepen students' scientific understanding, visualize abstract concepts, and foster research skills through interactive modeling platforms such as PhET. Furthermore, in the national education system, there is a shortage of systematic implementation of PhET simulations into curricula, evaluations of their effectiveness, and training of future teachers to work with such tools. This research aims to address these gaps and propose potential solutions.

RESEARCH METHODOLOGY

This study aimed to determine the effectiveness of using PhET simulations within the STEM approach in teaching atomic physics. The research was conducted based on pedagogical practice and carried out directly within the educational process.

The following PhET interactive simulations were selected and integrated into the teaching process: Rutherford Scattering, Models of the Hydrogen Atom, Blackbody Spectrum, and Fourier: Making Waves. Through these simulations, students explored the structure of the atom, energy levels, spectral radiation laws, and wave phenomena.

RESEARCH FINDINGS

The study revealed that PhET interactive simulations can be effectively used within the STEM framework to teach topics in atomic physics. In particular, visualizing hydrogen atom models allowed students to grasp abstract concepts in a clear and comprehensible manner. The integration of science, technology, engineering, and mathematics into the learning process enhanced students' interest in the subject and contributed to the development of their critical thinking, modeling, and research skills.

With the help of PhET simulations, learners were able to understand the evolution of atomic structure step-by-step, while independently performing tasks such as observation, comparison, and drawing conclusions. This approach not only facilitated knowledge acquisition but also allowed students to apply what they had learned in practical contexts. Moreover, for teachers, these tools provided opportunities to diversify lesson plans and modernize instructional methods.

Overall, the use of PhET models within the context of STEM education proved to be an effective and accessible method that meets the demands of modern education.

For instance, the topic “Blackbody Spectrum” in the PhET simulation can serve as a valuable example.

A blackbody is an idealized physical model that completely absorbs all incident electromagnetic radiation and emits radiation solely based on its temperature. Studying the spectrum of a blackbody holds significant importance in physics, particularly in the fields of thermodynamics and quantum mechanics. Explaining this phenomenon to students requires visualization and experimental modeling. For this purpose, the PhET simulation serves as a highly effective educational tool.

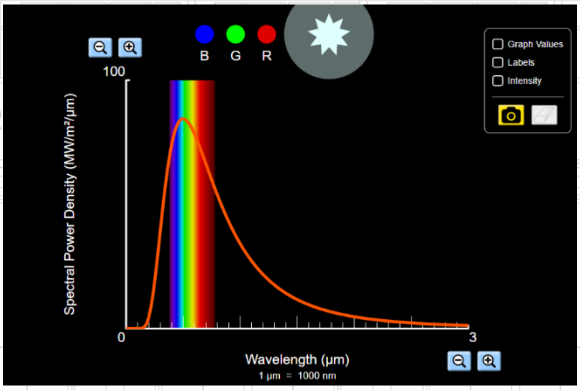

Figure 1. PhET Simulation [9]

Using the Blackbody Spectrum simulation from PhET [9], students can visually observe the relationship between an object’s temperature and its radiation spectrum. Solving problems based on the topic of blackbody radiation helps learners practice calculating actual physical quantities. Examples of problems based on Wien's Law and their solutions can be presented.

Problem: At what wavelength does a body with a temperature of 6000 K emit radiation most intensely?

$$\lambda_{max} = \frac{b}{T}$$

Where: b = $2.898*10^{-3}$m*K

$$\lambda_{max} = \frac{2.898*10^{-3}}{6000} = 4.83*10^{-7}\text{м} = 483\ \text{нм}$$

The peak radiation wavelength is 483 nm, which lies in the blue-green region of the visible spectrum.

PhET models allow students to observe physical processes in real time, manipulate parameters, and visualize the results dynamically. For example, in the Blackbody Spectrum simulation, students can change the temperature and observe how the radiation curve shifts accordingly.

This simulation can also be used to explain the structure of the atomic nucleus, alpha particle scattering, and the significance of Rutherford's experiment.

One of the most important experiments in the study of atomic structure is Ernest Rutherford's alpha-particle scattering experiment conducted in 1911. This experiment disproved the earlier "plum pudding model" of the atom and laid the foundation for the nuclear model. PhET simulations serve as an excellent tool to help students clearly understand this phenomenon.

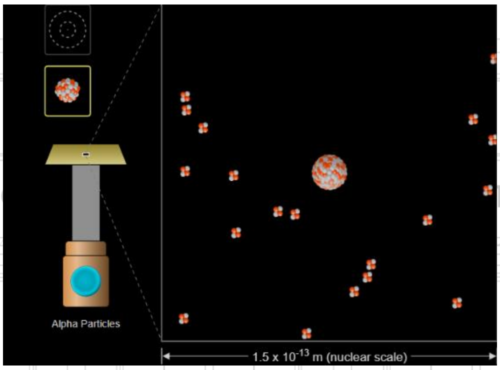

Figure 2. Rutherford Experiment in the PhET Simulation [10]

The "Rutherford Scattering" [10] simulation allows students to visually observe how alpha particles scatter when passing near an atomic nucleus. In Rutherford's scattering experiment, most alpha particles passed straight through, while some were deflected at large angles. These results provided strong evidence that atoms have a small, dense, positively charged nucleus at their center.

In the PhET simulation, this very phenomenon is modeled: as an alpha particle approaches the nucleus, it is deflected due to the Coulomb repulsion. As the nuclear charge increases, the scattering angle also becomes larger—accurately reflecting the real experimental outcomes.

Thanks to the PhET simulation, Rutherford scattering is no longer just a theoretical concept, but a visual, dynamic, and student-driven experience. This approach enhances learners' engagement with the subject and fosters a deeper understanding of physical laws.

Through the "Fourier: Making Waves" [11] PhET simulation, students are also able to explore complex wave motions as a sum of simple harmonic waves. When only the first harmonic (A_1) is active and its amplitude is set to 1.5, the resulting wave appears in a pure sinusoidal form. This corresponds to a fundamental wave at the base frequency — representing the pure first harmonic.

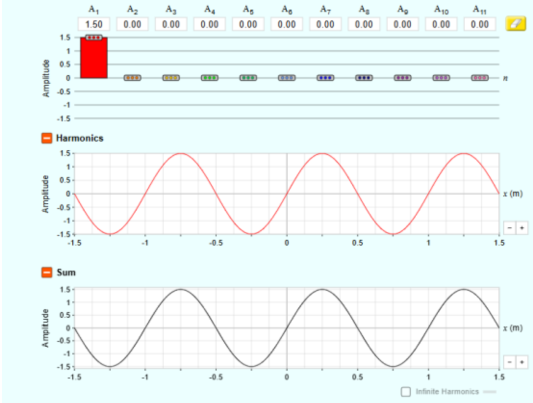

Figure 3. Fourier: Making Waves [11]

In the Harmonics section, the first harmonic is represented in red, while the Sum graph displays the actual shape of the resulting wave. Since additional harmonics (A_2, A_3, etc.) are not activated, the overall waveform remains a simple sine wave. This outcome illustrates that the most basic foundation of any complex signal is a sinusoidal wave at the fundamental frequency.

This model can be connected to real-life examples such as sound analysis in music, processing of electrical signals, vibrational motion, as well as heat and light propagation — thereby increasing students' practical interest in the topic.

The use of PhET simulations has been experimentally proven to positively impact the academic performance of students in STEM fields. These visual and interactive technologies demonstrate their effectiveness in mastering theoretical knowledge through quantifiable results [7].

Staneski also emphasizes that interactive modeling tools such as PhET are highly beneficial in teaching physics in combination with STEM and problem-based learning methods, as they boost student engagement and facilitate independent thinking and understanding [8].

Using PhET simulations within the STEM approach offers an effective and engaging way to teach atomic physics in depth. Students are able to grasp theoretical concepts through concrete models and approach physical laws from a researcher's perspective. The integration of STEM increases their interest in science and develops their logical reasoning, laboratory, and creative skills. PhET models help transform learners from passive listeners into active participants.

CONCLUSION

The results of this study show that integrating PhET simulations with the STEM approach can serve as an effective tool in teaching atomic physics. Interactive models helped students comprehend complex concepts more easily, actively engage in lessons, and develop scientific thinking skills. By using simulations such as Rutherford Scattering, Hydrogen Atom, Blackbody Spectrum, and Fourier: Making Waves, students were able to visually explore atomic structure, energy levels, and spectral and wave phenomena.

This approach not only enhanced students' interest in the subject but also helped foster practical and research-oriented skills. Therefore, the systematic integration of PhET simulations into the learning process is one of the key strategies for ensuring high-quality, modern physics education.

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