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Design of a virtual environment with interactive simulations for the teaching of mechanic

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Abstract

Training in mechanics at both high school and university levels is often constrained by the lack of adequately equipped laboratories, as much of the necessary equipment is prohibitively expensive. To address these limitations, a virtual environment was developed that integrates interactive simulations of phenomena such as free fall, uniform rectilinear motion, pendulums, inclined planes, and the Atwood machine experiment. Each simulation was implemented as an independent applet with parameter controls (mass, gravity, angle, velocity, etc.) linked to scripts that generate real-time graphs of selected variables. These applets are embedded in a responsive website, organized into sections on theory, user guides, simulations, and references, accessible via computers and mobile devices. The proposed activities enable students to calculate slopes, determine percentage errors, and compare theoretical and simulated values of gravitational acceleration in different planetary environments. Analysis of pedagogical use suggests that these simulations enhance motivation, visual understanding, and learning autonomy, particularly in resource-limited contexts. It is recommended that evaluation be expanded to additional institutions, qualitative studies of user interaction be incorporated, and personalization through artificial intelligence be explored.

Keywords: interactive simulations, Newtonian mechanics, autonomous learning, web platform, virtual experimentation

INTRODUCTION

Physics, particularly mechanics, forms the foundation for explaining and predicting both every day and technological phenomena. Traditionally, the study of physics–especially at the secondary and university levels–has posed a significant challenge for many educators (Jaime & Leonel, 2024). The discipline frequently addresses technical and abstract concepts, employing a mathematical language that can feel alien to intuition derived from everyday experience. Concepts such as subatomic particles or the properties of space-time at high velocities lie beyond this intuition. Such complexity and abstraction can result in students feeling bored or even frustrated by their inability to grasp the presented content (Jaime & Leonel, 2024; Lino-Calle et al., 2023). Indeed, the subject's inherent difficulty and abstract nature are often cited as reasons for students' lower interest in physics compared to other disciplines. Overcoming traditional approaches that prevent students from connecting physics knowledge to real-world contexts and everyday applications remains a major educational challenge (Nicolás Durán et al., 2024).

Although in many educational programs theoretical instruction is ideally complemented by laboratory experiments to enhance understanding, in many undergraduate education institutions the lack of appropriate physical spaces, adequate materials or equipment (often prohibitively expensive), or the need for specialized personnel and teacher training limits the implementation of in-person laboratory practices (Lino-Calle et al., 2023; Vidal & Menezes, 2019). This absence of practical learning environments creates significant gaps in students' experimental training.

To address these limitations and respond to the need for experimental practice, both students and educators have increasingly turned to digital simulation platforms.

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Contribution to the literature

- This paper contributes a ready-to-use virtual environment that integrates pedagogically structured, interactive simulations for teaching mechanics, offering a practical alternative for institutions with limited laboratory infrastructure.
- The platform explicitly operationalizes a STEM approach in physics education, where each simulation is designed to engage students in the interconnected processes of scientific exploration, technological manipulation, engineering design, and mathematical modeling.
- The study adds pilot-level empirical evidence indicating that such a platform can enhance student motivation, improve conceptual understanding, and foster autonomous learning in resource-constrained educational contexts.

These tools offer interactive environments designed to recreate physical phenomena in an accessible and pedagogically effective manner, assisting educators in immersing students in a simulated experimental research context (Álvarez-Siordia et al., 2025; Hurtado Espinosa et al., 2025; Vidal & Menezes, 2019). Simulation programs enhance the understanding of physical phenomena by integrating graphical elements and animations within a unified interface. This, coupled with students' inherent interest in digital technologies, can make the teaching–learning process more effective and engaging. Unlike simple animations, computer simulations enable data generation and analysis based on hypothetical scenarios, thereby supporting the development of intuitive or foundational understanding necessary for grasping physical principles. Moreover, simulations serve as a valuable resource for learning technical and abstract concepts, offering students increased freedom to explore, observe, and analyze specific phenomena (Jaime & Leonel, 2024).

Among the technological tools available, GeoGebra stands out due to its open-access and versatile nature. This software integrates interactive geometry, algebra, calculus, and statistics into a single, user-friendly platform suitable for all levels of mathematics and science education. GeoGebra enables the creation of high-quality, precise geometric constructions through a simultaneous graphical and algebraic interface, which can be customized in terms of colors, styles, and layouts. It also supports the generation of graphs, spreadsheet management, and includes advanced mathematical tools such as a computer algebra system (Dias et al., 2021). The dynamic linkage among algebraic, geometric, and numerical representations is particularly valuable for teaching physics (Solvang & Haglund, 2021).

This category of dynamic geometry software enables the construction, tracing, and manipulation of geometric figures, with the capability to represent real-valued, derivative, integral functions, and other mathematical objects (Gutiérrez et al., 2017; Ziatdinov & Valles, 2022). Its capacity to connect algebraic expressions with geometric representations–where modifications to variables result in changes to the structure or position of geometric objects–makes it a valuable instructional resource. This feature can be creatively adapted to the study of physics problems, particularly those in mechanics.

GeoGebra's flexibility makes it applicable across various disciplines. Although its primary focus is mathematics education, it is also well-suited for developing interactive simulations in the sciences, including chemistry and physics (Dias et al., 2021). For example, optics experiments can be designed to visualize Malus's law or interference phenomena (Camacho-Mendoza & Racedo-Niebles, 2022; Xu et al., 2024). In addition, one can model a solenoid to analyze its internal and external magnetic fields, plot field lines, and calculate field density according to Ampère's law (Chávez et al., 2025). These capabilities demonstrate how the software can be creatively adapted to teach physical phenomena by combining interactive geometric and algebraic constructions. GeoGebra also enables the development of interactive simulations for more complex phenomena, such as simple or damped harmonic motion, as demonstrated in recent studies (Luque-Alvernia et al., 2022).

Wix, on the other hand, offers a drag-and-drop editor, customizable design options, built-in hosting, and search engine optimization (SEO) tools, enabling educators to create intuitive web pages where they can embed GeoGebra applets via iframes and organize learning resources in an accessible manner. GeoGebra allows users to save their developed simulations on its official site, providing the ability to create personalized environments for uploading multiple simulations and making them directly accessible online. This enables teachers to incorporate additional activities and resources, such as videos, images, and class notes, while integrating geometric constructions and animations created within the GeoGebra platform.

In addition to GeoGebra, other digital technological tools have been widely adopted for science education, particularly in the teaching and learning of physics. Among these, PhET interactive simulations–developed by the University of Colorado–stands out as one of the most widely used resources in physics instruction (Dias et al., 2021; Lino-Calle et al., 2023 Nicolás Durán et al., 2024). PhET simulations are interactive tools that enable users to establish connections between real-world phenomena and fundamental scientific concepts and have been studied for their capacity to engage students in virtual experimental exploration (Lino-Calle et al., 2023; Nicolás Durán et al., 2024). The PhET project aims to provide a suite of simulations that support improvements in science teaching and learning. It includes simulations relevant to mechanics, specifically addressing content on force and motion within Newtonian mechanics. The platform allows parameter manipulation with instant observation of resulting changes, making abstract concepts more tangible and comprehensible (Lino-Calle et al., 2023).

The study by Souza et al. (2024) describes SimuFísica as a collection of simulation applications designed for physics education. This platform is multilingual and cross-platform, offering simulations that cover a wide range of topics. The simulators can be accessed online or installed locally, providing flexible access options. The use of SimuFísica in the classroom can facilitate interactive visualization of phenomena, deepen understanding of abstract concepts, and support the conduct of virtual experiments. This demonstrates the scope of a platform specifically dedicated to hosting and providing a comprehensive collection of interactive simulators for teaching purposes (Souza et al., 2024).

The integration of digital simulations into the curriculum aligns with the science, technology, engineering, and mathematics (STEM) approach, which promotes interdisciplinary learning grounded in real-world problem solving and the development of critical and collaborative thinking skills (Kefalis et al, 2025; Magana et al., 2024). Through these tools, students can explore physical concepts while simultaneously strengthening technological and engineering competencies, thereby facilitating the transition from mathematical theory to practical application. To optimally support this learning process, it is recommended to design activities that integrate virtual experimentation with design challenges, encourage teamwork in the development of solutions, and promote metacognitive reflection on the results obtained (Ziatdinov & Valles, 2022).

From the STEM perspective, learning is conceived as an integrated process in which scientific theory, technological thinking, engineering design, and mathematical reasoning converge within real-world projects. This approach fosters students' ability to formulate questions, design experiments, and apply digital tools to address practical challenges (Khaeruddin & Bancong, 2022; Lino-Calle et al., 2023; Magana et al., 2024). By incorporating interactive simulations, educators not only convey physical concepts but also help develop transversal skills such as basic programming, data analysis, and collaborative work. In this way, simulation becomes an active learning platform in which students move beyond being passive recipients of information to become investigators of their own educational process.

The primary objective of this work was to design and present a web platform of interactive simulators developed with GeoGebra. Complementarily, an exploratory pilot study was conducted with pre-service teachers to assess the perceived usability and pedagogical contribution of the platform; the pilot results inform the proposed improvements and recommendations for future studies.

METHODOLOGY

The construction of the platform was undertaken on two complementary fronts: the development of simulations in GeoGebra and the assembly of the website using Wix.

The simulations were developed by following the STEM approach in a coordinated and interconnected way, in which each phase (science, technology, engineering, and mathematics) is articulated with the others rather than functioning independently. In the science phase, students interact with a virtual physics laboratory, manipulating variables and observing system behavior in real time, which reinforces experimental understanding through the formulation and testing of hypotheses. In the technology phase, the GeoGebra-based platform provides access to the source code of each applet, allowing it to be inspected, adjusted, and reused so that students can create and customize their own models. The engineering dimension is addressed when students must design and adapt simulations to practical requirements–for example, optimizing the accuracy of readings, selecting appropriate controls and visualizations, and validating performance under different conditions–which involves planning the applet's architecture and ensuring its robustness. Finally, in the mathematics phase, protocols are established for extracting data from simulations (graphs and tables) and applying theoretical equations to compare results, thereby strengthening students' numerical modeling and quantitative analysis skills. This approach ensures that students not only understand the theoretical foundations of the experiments but also develop programming, system design, and mathematical analysis skills in an integrated way.

GeoGebra Simulations

1. GeoGebra was employed as a dynamic geometry environment to model classical mechanical phenomena. Leveraging its integration of geometric and algebraic processors, interactive constructions were developed to represent mass-spring systems, pendulums, blocks on inclined planes, circular motion, free fall, parabolic motion, and linear motion at constant speed.

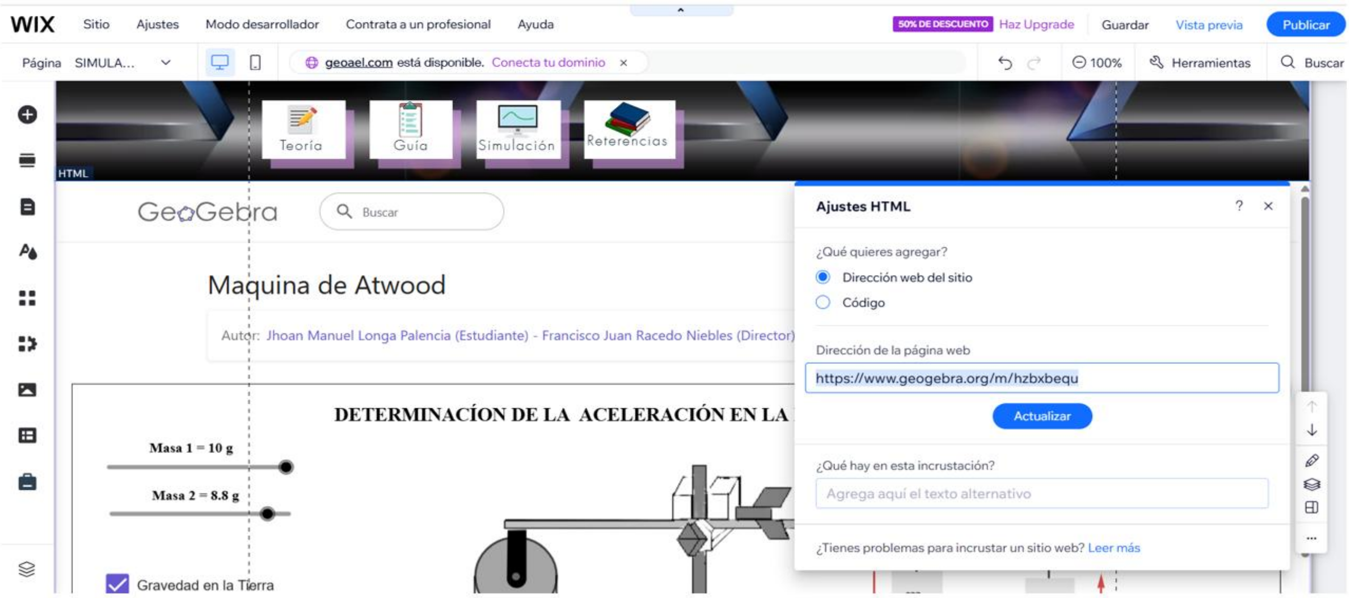

Figure 1. HTML embed component configuration window in Wix, where the URL of the GeoGebra iframe is inserted to embed the Atwood machine simulation (Source: Authors' own elaboration)

2. To enhance parameter control, GeoGebra scripts (Castillo & Prieto, 2018) were used to link sliders and text fields to mathematical variables. In this way, modifying values such as mass, spring constant, or angle of inclination automatically updated position, velocity, and energy graphs in real time.
3. Each simulation was designed as a standalone applet and exported as an iframe using GeoGebra's "share link" feature, ensuring compatibility with web browsers and facilitating easy integration.

Website on Wix

1. Wix was selected as the website creation platform due to its drag-and-drop visual editor, which enables pages to be built without the need for programming by simply placing elements such as text, images, or buttons in the desired location. In addition, it offers integrated hosting, meaning the site is automatically hosted on Wix's servers, eliminating the need to contract external services.
2. Using the HTML embed component, GeoGebra iframes (elements that display external content within a web page) were embedded, with widths and proportions configured to ensure optimal viewing across different devices while maintaining the design's responsive adaptability (**Figure 1**).
3. Using the HTML embed component–a tool that enables the insertion of HTML code snippets into a Wix page–GeoGebra iframes (elements that display external content within a web page) were embedded. GeoGebra is an interactive platform for mathematical and physical simulations. Widths and proportions were configured to ensure optimal viewing across different devices while maintaining the design's responsive adaptability (**Figure 1**).
4. The simulations were organized into mechanical categories–for example, uniform rectilinear motion (URM), free fall, and parabolic motion–which are represented in the main menu, a navigation bar that enables users to easily access each section of the site (**Figure 1**). Each simulation page was designed with three virtual tabs–theory, guide, and simulation–which facilitate understanding of the content from different pedagogical perspectives (**Figure 2**).
5. Additionally, the SEO tools available in Wix were leveraged to properly configure meta tags, descriptions, and navigation links. These optimizations facilitate indexing by search engines such as Google and improve discoverability for users seeking educational resources.

Study Design

The students who participated in this study were enrolled in a diploma program on physics teaching, aimed at pre-service mathematics teachers, and offered by a public university in northern Colombia. The instructors invited the students to interact with a set of virtual simulations, used after some theoretical classes either as preparatory activities for different hands-on laboratory practices or as a complement to labs that were not available at the university. The evaluated practices covered various mechanical topics, such as rectilinear motion, force table (statics/vector composition), inclined plane, and the use of measuring instruments (Vernier

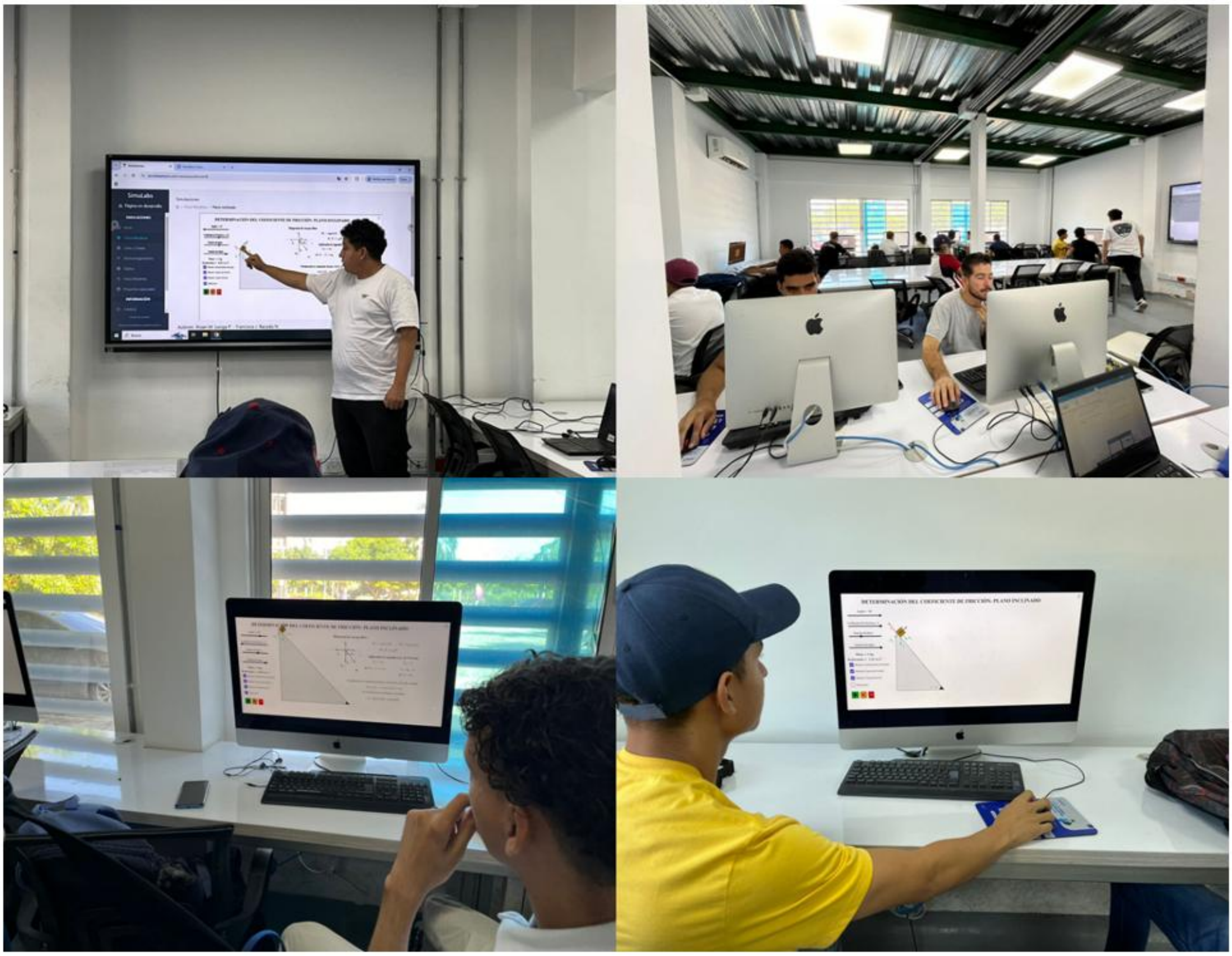

Figure 2. Classroom implementation of virtual simulations: the instructor presents the activity objectives and guides the students in the use of the online platform (top left) & the students work individually and in pairs with some of the simulators (top right and lower panels) (in this way, theoretical explanation is combined with exploratory practice and collaborative learning) (Source: Field study)

caliper). For each practice, activity guides and orienting questions were provided, either integrated into the platform or directly embedded in some of the simulators, which were later discussed in class. This sequence was intended to activate prior knowledge, encourage autonomous conceptual exploration, and prepare the understanding of the physical model before the real experiment, including the handling of instruments such as the dynamometer, caliper, and micrometer screw.

The study followed an exploratory design with a small group of university students (N = 20). The participants were selected from a single course, on a voluntary basis, and included both male and female students in advanced semesters of a mathematics teaching degree. The activity was guided by an instructor who supervised the interaction with the simulations and provided clarifications when necessary. **Figure 2** shows the students and the instructor working with the simulation in the classroom context.

Structure and interaction flow

In each of the practices carried out, a logical sequence was followed. First, an initial manipulation of parameters was performed; subsequently, the guided activity was developed; then, students engaged in data acquisition; later, they responded to the guiding questions; and finally, they carried out a process of analysis and reflection. In the exploratory pilot, this general structure was implemented in five phases:

1. **Initial manipulation of parameters:** Students began by adjusting input variables, depending on each simulator. In some cases, these were dynamic magnitudes, such as mass, velocity, or angle of inclination; in others, instrumental parameters such as the scale of a caliper or the sensitivity of a dynamometer. This first contact promoted familiarity with the environment and activated prior knowledge.
2. **Execution of the guided activity:** Once the initial parameters were configured, the students carried

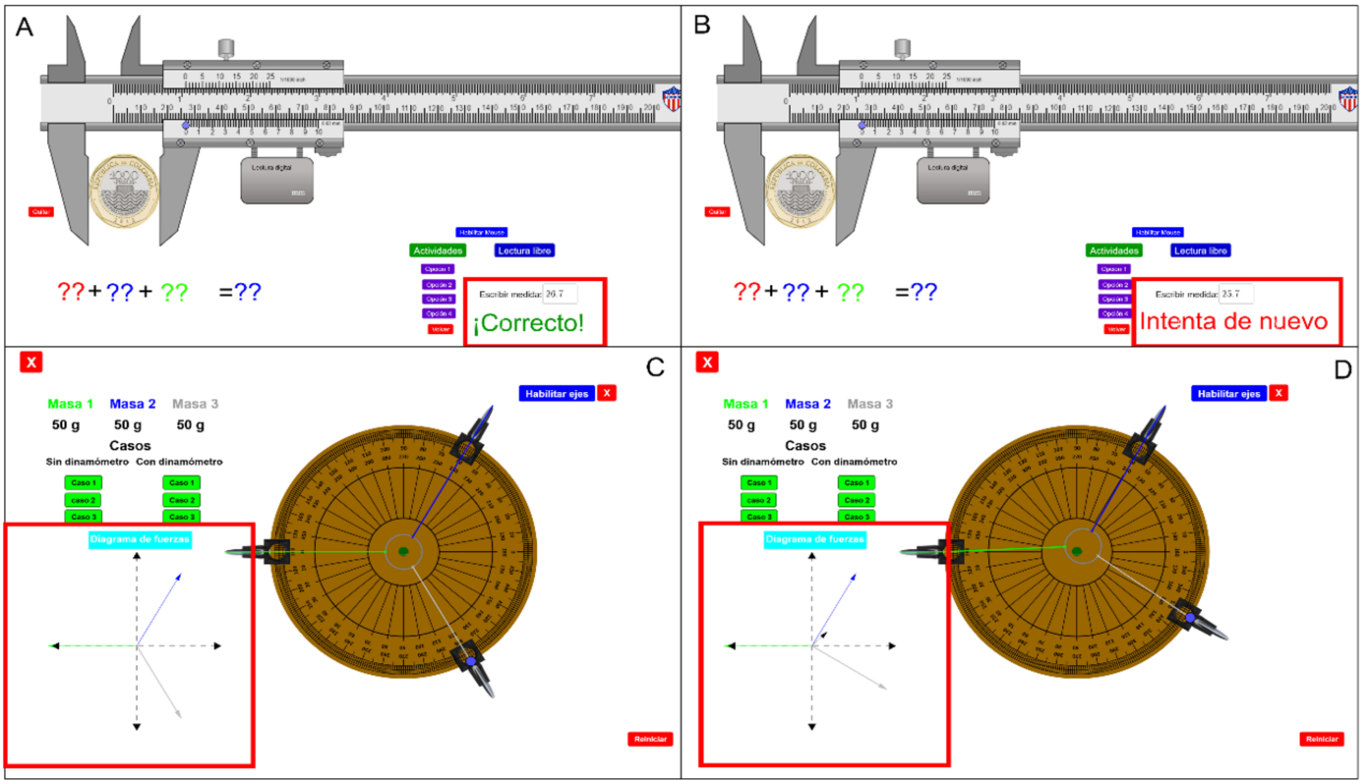

Figure 3. Feedback modalities in the simulations: (A) Vernier correct measurement entry (message "¡Correcto!"), (B) Vernier incorrect measurement entry (message "Intenta de nuevo"), (C) force table state 1 showing the dynamic vector diagram, & (D) force table state 2 with immediate update of the vector diagram (red boxes highlight the areas of visual feedback and/or input validation) (Source: Authors' own elaboration)

out the experience following instructions that could be integrated into the simulator itself or into the "Guide" section of the webpage. This stage ensured that the manipulation was not random, but oriented toward a didactic goal (e.g., verifying force composition, correct instrument reading, or comparing trajectory with equations of motion).

3. **Data acquisition by students:** During the activity, the simulators allowed the collection of information in different forms: real-time graphs (position-time, velocity-time, and energy-time), exportable data tables, or numerical readings from virtual instruments. Students were responsible for compiling and organizing these data, either for immediate calculations or for later discussions.
4. **Response to guiding questions:** Each simulation was complemented by a set of orienting questions, located either within the platform or in the simulator itself. These questions invited students to interpret the obtained results, compare them with theoretical models, and reflect on the limits of the simulation in relation to the real physical experiment.
5. **Analysis and reflection:** Finally, students contrasted their observations with the concepts covered in class and shared collective conclusions. In the exploratory pilot, this phase also included the application of a five-item Likert-type survey on usability, motivation, and learning support, as well as classroom observations to record behaviors, difficulties, and interactions among peers and with the instructor.

Differentiated feedback and the STEM approach

Within the STEM framework, immediate and specific feedback constituted a key technological and pedagogical component that supported the dimensions of science, technology, engineering, and mathematics:

1. **Science:** Feedback facilitated the controlled observation of physical relationships, helping students to formulate and test hypotheses.
2. **Technology:** The interfaces of each simulation and the automated routines displayed real-time results and logged data, reducing the technical burden so that students could focus on interpretation.
3. **Engineering:** Students applied design criteria when adjusting simulations or experimental setups (e.g., choice of scales and calibration of virtual instruments).
4. **Mathematics:** The recorded outputs (graphs and tables) enabled students to quantitatively model results and compare them with theoretical predictions.

Figure 4. Overview of the site's home page (the upper window that says "MECHANICS" can be seen, which allows quick access to the interactive simulations) (Source: Authors' own elaboration)

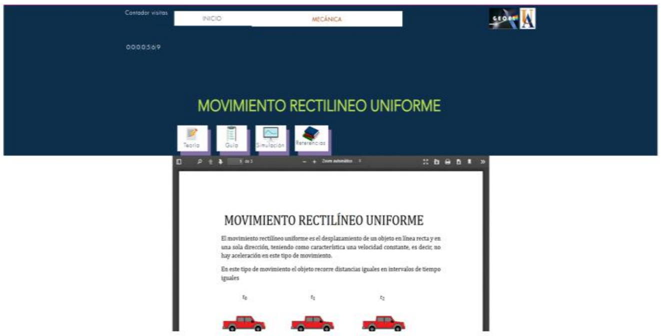

Figure 5. Common structure of simulation pages (theory, guide, simulation, and references tabs are displayed) (Source: Authors' own elaboration)

The feedback modalities were not uniform across all simulations. Two examples are highlighted in this work (Figure 3):

1. **Force table (dynamic visual feedback):** When magnitudes or directions were modified, the real-time graph updated the resultant vectors and their components, allowing immediate observation of vector composition and decomposition.
2. **Vernier caliper (input validation activity):** Students entered the measured values in the virtual instrument. The system validated the responses and provided immediate correct/incorrect feedback along with hints, fostering measurement accuracy and self-assessment.

These feedback modalities (dynamic visual vs. input validation) were intentionally incorporated to support different pedagogical goals: the former fostered the understanding of vector relationships and continuous models, while the latter emphasized instrumental skills and measurement accuracy.

RESULTS AND DISCUSSION

The implementation of the educational website focused on interactive simulations of mechanical phenomena addresses the need for accessible, visual tools to complement theoretical learning. By leveraging the development environment provided by Wix and integrating GeoGebra applets, a simple, visually appealing, and functional navigation space was designed to support the teaching of mechanical physics. This paper presents a characterization of the site's main sections along with a pedagogical analysis of selected simulations.

General Website Environment

The website developed on Wix features a clear, streamlined interface optimized for desktop devices. From the homepage, users can easily navigate to the different sections: introduction, simulations, resources, and contact. The clean design and structured landing page layout enhance user orientation from the initial interaction.

Available Simulations Section

The Simulations section is the core of the digital environment. It is organized into six thematic modules corresponding to classical mechanical phenomena: URM, free fall, parabolic motion, uniform and accelerated circular motion, the inclined plane, and the Atwood machine (Figure 4).

Each simulation is structured on an individual page that includes four tabs (Figure 5):

1. **Theory:** contextualizes the physical phenomenon, its concepts, includes the deduction of equations and schematic graphs.
2. **Guide:** Presents step-by-step instructions on how to operate the simulation, along with objectives and analysis questions.
3. **Simulation:** Integrates the interactive GeoGebra applet, where parameters can be modified and the results can be observed.
4. **References:** Provides supplementary bibliography and links to external resources.

Analysis of Specific Simulations

Free fall

The simulation of free fall represents a fundamental scenario for understanding the behavior of a body subjected exclusively to the acceleration of gravity, without the intervention of external forces or air resistance (Chulde Ruano, 2024; Obando Paredes, 2024). According to classical theory, this type of motion is a uniformly accelerated rectilinear motion, and is described by Eq. (1):

$$h = \frac{1}{2}gt^2, \quad (1)$$

where h is the height from which the object falls or is dropped, g is the acceleration due to gravity, and t is the time it takes to reach the ground. This relationship can be cleared to obtain the value of g using Eq. (2):

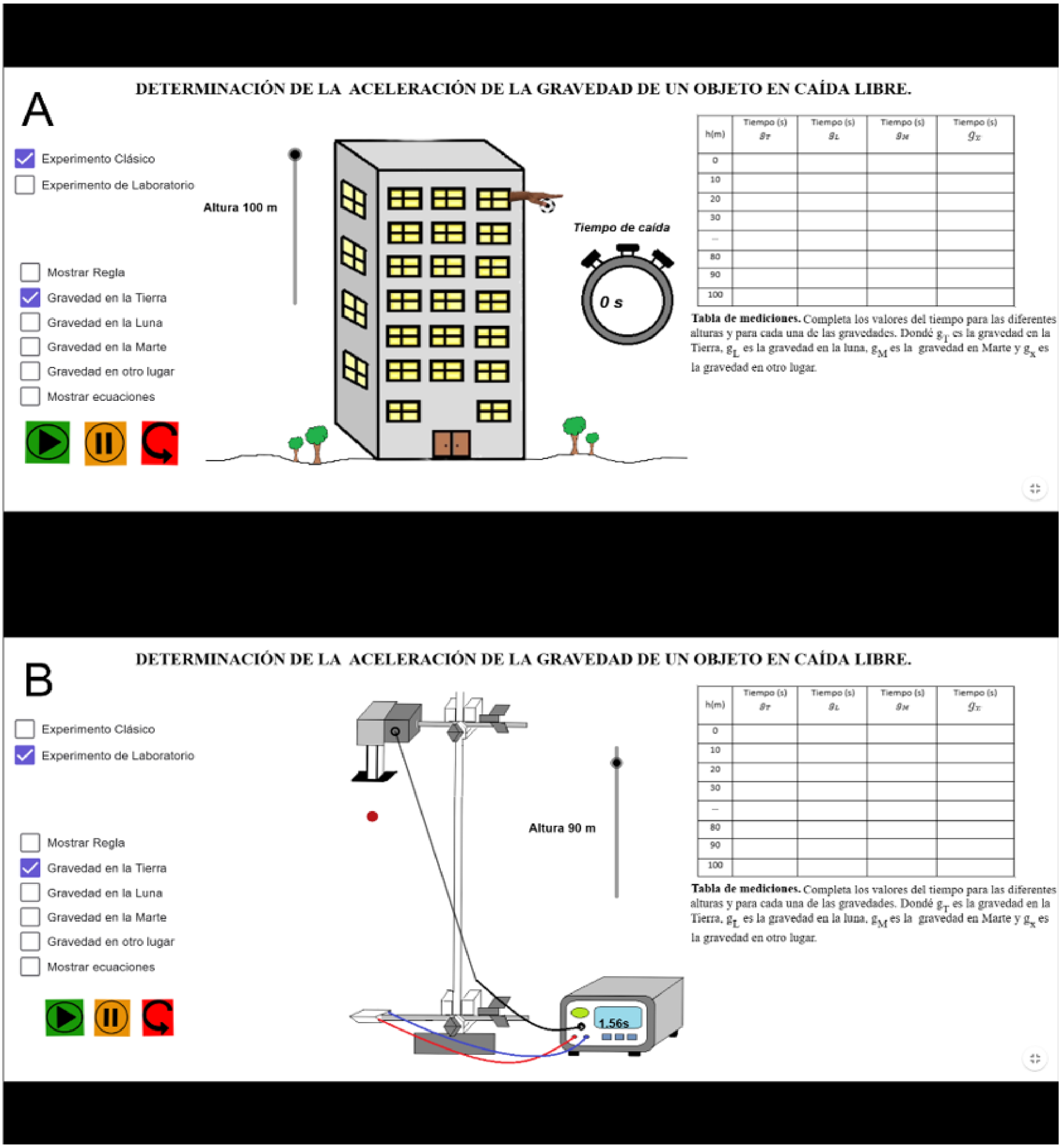

Figure 6. Free fall simulation interface: (A) representation inspired by the classical experiment from a building, in the style of Galileo Galilei & (B) representation of a typical laboratory setup with electromagnet, pellet and timer (Source: Authors' own elaboration)

$$g = \frac{2h}{t^2}. \qquad (2)$$

The simulation allows the student to verify this equation by comparing the theoretical value of gravity with an experimental value obtained virtually. To this end, two complementary experiences are proposed in the simulator: Simulating the classic experiment and the experiment carried out in the laboratory.

Simulation of the classical experiment (part A in Figure 6): Inspired by the experiment that, according to tradition, Galileo Galilei carried out from the Tower of Pisa, this simulation presents a building from which a ball is dropped from different heights (0 to 100 m). The user can:

1. Select the height with a slider.
2. Modify the gravity of the environment (earth, moon, mars, or a mysterious gravity g_x).
3. Control crash time with play, pause, and restart buttons.

This part of the simulation allows us to observe that, in the absence of air resistance, all bodies fall with the same acceleration, regardless of their mass, which is a fundamental principle of classical mechanics.

Laboratory experiment simulation (part B in Figure 6): It recreates an environment closer to a school lab, where a pellet is held by an electromagnet and falls when the system is deactivated. The fall time is measured by a digital counter that stops when the pellet hits a switch placed at the bottom. The height between the two points can be measured by means of a ruler visible on the screen.

This type of virtual assembly is based on real systems that can be found in educational and commercial laboratories, such as those offered by companies such as PASCO (n. d), Leybold Didactic (n. d.), and PHYWE (n. d.).

Proposed experimental activities: The simulation guide guides the user through a series of measurements and calculations. Some of the activities are:

1. Measure fall time from a height of 100 m under earth's gravity.
2. Repeat the experience by varying height and gravitational environment.
3. Calculate the value of g for each case.
4. Compare the value obtained with the theoretical value of and calculate the percentage error$g$.
5. Perform the same procedure under lunar and Martian conditions.
6. Infer, using the data to which planet the unknown gravity belongs g_x.
7. Provide a reasoned opinion about the simulation experience.

This set of activities not only reinforces the understanding of free-fall kinematics, but also enhances critical thinking by motivating the student to question results, analyze discrepancies, and justify conclusions; develops computational thinking by becoming familiar with the parameterization of variables, the automation of calculations and the interpretation of data generated by the software; it fosters analytical and comparative skills by contrasting different scenarios and estimating uncertainties; and promotes the transfer of knowledge from the virtual environment to the real laboratory, preparing the student to design and validate physical experiments.

Uniform rectilinear motion

URM is characterized by the displacement of a body in a straight line with constant velocity, that is, without acceleration (Chulde Ruano, 2024; Obando Paredes, 2024). In this motion, the object travels equal distances at equal times. Its mathematical description is given by the Eq. (3):

$$x(t) = vt + x_0, \tag{3}$$

where x is the final position of the object, x_0 is the starting position, v is the velocity (constant), and t the time elapsed.

Description of the simulation (Figure 7): The simulation allows the user to experiment with the principles of URM through an interactive representation that shows a car moving on a flat surface. The environment includes:

1. A starting position slider, which allows you to establish where the vehicle starts from.
2. A speed slider, with a range between 0 and 30 m/s.
3. Start, pause, and restart buttons that control the execution of the simulation.
4. A panel where the values of elapsed time and distance travel are shown in real time.
5. A position vs time graph, which is dynamically updated as the car's movement progresses.

The simulator environment facilitates the understanding of the concept of constant speed and its graphical representation, eliminating practical real-world difficulties, such as friction, human error in measurement or imperfections in experimental material.

Activities proposed in the guide: The simulation is designed with activities that stimulate graphic, numerical and conceptual analysis of movement. Some of them include:

1. Calculation of the slope of the graph x vs t, using any two points.
2. Physical interpretation of the slope, associating it with speed.
3. Comparison between graphics and simulator speed, including percentage error calculation.
4. Stopping the vehicle at different times, to calculate instantaneous speeds and compare with the average.
5. Analysis of graphical variation when modifying the speed of the object.

These activities allow a progressive and reflective approach to the physical phenomenon, promoting skills of graphic interpretation, experimental comparison and application of formulas in context. In addition, as it is a virtual environment, the simulation is reproducible at any time and place, which facilitates autonomous learning and systematic review of each step. This always available nature also promotes critical thinking, by allowing results to be compared in different sessions, and reinforces computational thinking, by encouraging the parameterization of variables, the automation of calculations and the generation of new scenarios quickly and easily.

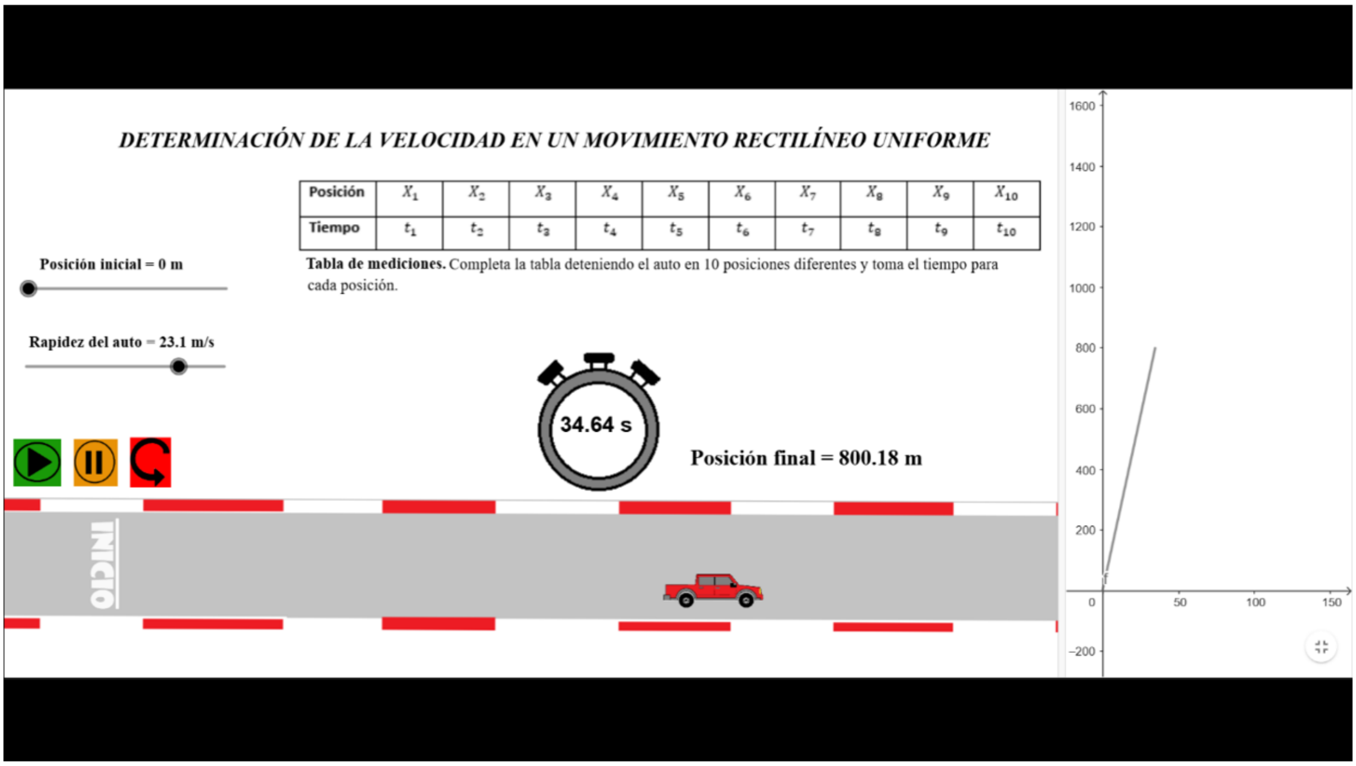

Figure 7. Simulation of URM: On the left, the vehicle is shown in motion & on the right, you can see the dynamic graph of position against time (controls for speed, starting position, and execute buttons are included) (Source: Authors' own elaboration)

Gallery of Complementary Simulations

In addition to the simulations analyzed in depth (free fall and URM), the virtual environment developed includes other fundamental representations for the teaching of classical mechanics (see **Figure 6**). Each of them is built with the same organizational structure (theory-guide-simulation-references) and responds to specific objectives within the physics curriculum in basic and secondary education. They are briefly described below.

Parabolic motion

This simulation makes it possible to study the movement of a projectile under the influence of gravity, launched with an initial velocity at a certain angle. The user can modify the launch speed and angle, observing how the maximum height, horizontal reach and trajectory of the body varies. A real-time representation of the parabolic trajectory is included, along with a graph of the position on the axes x and y as a function of time.

This content is essential for understanding the decomposition of motion into horizontal (URM) and vertical (free fall) components, as well as for relating kinematic variables.

Uniform circular motion

The uniform circular motion simulation represents an object moving at a constant speed on a circular path. The user can adjust the circumference radius and angular velocity, observing how these parameters affect the frequency, period, and trajectory of the object. Vectors of position, tangential velocity and centripetal acceleration are also displayed.

This simulation is especially useful for transitioning from linear to rotational analysis, integrating key concepts into circular kinematics (Chulde Ruano, 2024; Obando Paredes, 2024).

Inclined plane

The simulation enables the analysis of how the weight of an object decomposes on an inclined surface. The angle of the plane can be modified, as can the mass of the body. The simulation shows force vectors (normal, weight, parallel component) and can include or exclude the effect of friction.

This experience is ideal for introducing the concept of Newton's second law and for solving dynamics problems on inclined planes, common in introductory physics courses.

Atwood machine

The Atwood machine consists of a system of two masses connected by a rope that passes through a pulley. The simulation reproduces this system, allowing the masses to be modified and the dynamic behavior of the whole to be observed. A graph of acceleration and velocity is included, as well as the analysis of the net force on the system.

This simulation serves as a bridge between the study of forces, acceleration and the use of the free-body diagram, in addition to applying Newton's second principle to coupled systems (Chulde Ruano, 2024; Obando Paredes, 2024).

Vernier caliper

It allows the user to accurately measure internal and external diameters and depths, incorporating controls to move the jaws and display the reading in millimeters and fractions of a millimeter. This simulation reinforces the understanding of metrological instrumentation and the importance of accuracy in measurements.

Micrometric screw

It offers an interactive spindle and nonium scale display, showing the simultaneous reading of the main ruler and the nonium. It helps students practice interpreting micrometer readings and understand the concept of resolution.

Reaction time

It simulates a visual or sound stimulus and measures the time interval until the user's response (pressing a button), presenting statistics of several repetitions. It serves to introduce notions of neurophysiology and experimental methods in health sciences and psychology.

Forces table

It represents a small ring on which ropes with variable forces are fixed; The student adjusts voltages until the system is balanced and observes the resulting vectors in real time. This simulation facilitates the practice of free-body diagrams and the decomposition of forces in two dimensions.

Figure 8 shows the gallery view of the complementary simulations featured on the platform. Although each simulation represents a different phenomenon, they all contribute to a common goal: to strengthen active learning, visual comprehension and autonomous experimentation in students. These digital tools do not replace physical practice, but they complement it and often surpass it in conceptual clarity, especially in contexts where access to laboratories is limited.

Pedagogical Value of the Simulators

The use of simulators allowed students to focus on the fundamental relationships of physical models, reducing the initial complexity associated with handling equipment in a traditional laboratory. This simplified representation facilitated the generalization of various fundamental concepts in mechanics, such as the composition of forces, rectilinear motion, and the use of measuring tools, promoting the construction of abstract mental models that are essential for addressing more complex scientific contexts in advanced stages of education.

The simulators reduced the students' operational load by automatically generating values and displaying dynamic visualizations. This allowed learners to focus on interpreting results and the underlying scientific reasoning, rather than on the technical manipulation of equipment. Likewise, they fostered an algorithmic understanding of phenomena by showing how a logical sequence of steps leads to consistent results, introducing students to a culture of computational modeling that is key in STEM education.

To evaluate students' experiences with these simulations, a five-level Likert-scale questionnaire (very poor, poor, fair, good, and excellent) was administered. The results revealed a highly positive assessment: more than 80% of participants rated the experience as good or excellent, highlighting in particular motivation toward the activity (93%) and understanding of the concepts (87%). No responses were recorded in the "very poor" category, and only a small percentage fell into the "fair" category, especially in aspects related to the ease of manipulating parameters or the clarity of certain visualizations.

In the more specific scope of individual simulators, equally positive evaluations were obtained. For example, when students were asked about the free-fall simulator with the question: "Did the virtual free-fall practice help strengthen your understanding of the laws of uniformly accelerated motion?"–91% responded affirmatively, emphasizing the clarity with which they could relate position–time and velocity–time graphs to the real physical phenomenon.

In the case of the inclined plane, the majority of participants (88%) indicated that the simulation facilitated the identification of the forces involved and the analysis of motion under different angles, which strengthened their ability to anticipate results in the in-person practice. Similarly, the URM simulator was regarded as a key resource for understanding the linearity of kinematic graphs, with 90% of participants giving positive responses. Students highlighted the ability to manipulate parameters and observe in real time the direct relationship between displacement and time, which reinforced their conceptual interpretation of basic kinematics. Regarding virtual instruments, such as the micrometer screw gauge, 85% of respondents stated that the simulator promoted familiarity with reading measurements and validating results, reducing the insecurity typically associated with the first contact with the real instrument. Taken together, these perceptions show that the simulators were not only valued in general as motivating and useful experiences but also showed pedagogical effectiveness in the understanding of key

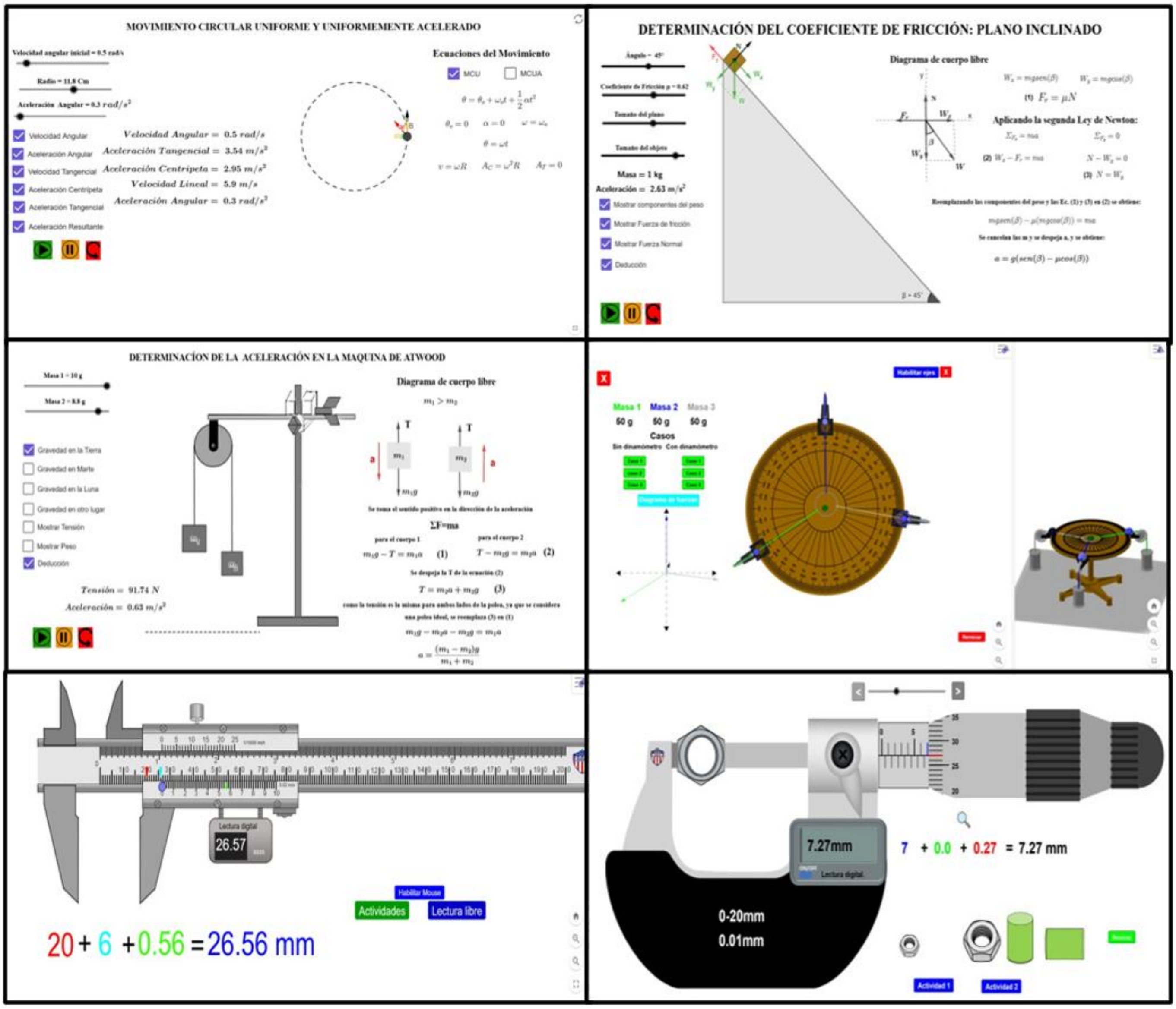

Figure 8. Gallery view of the complementary simulations featured on the platform: uniform and accelerated circular motion, inclined plane (friction), Atwood machine, forces table, Vernier caliper, and micrometric screw (Source: Authors' own elaboration)

concepts in mechanics and in the strengthening of instrumental skills.

From a didactic perspective, these findings suggest that the use of interactive simulations not only facilitates the comprehension of complex phenomena but also promotes the development of skills associated with computational thinking. Automation is reflected in the resource's ability to execute dynamic processes and real-time representations without continuous intervention, allowing students to immediately observe the effects of their manipulations. Abstraction, in turn, is evident in the simplification of experimental setups by focusing attention on the essential components of the physical–mathematical model. This integration between technological simulation and computational reasoning contributes to the creation of active and meaningful learning environments, aligned with the current demands of science and engineering education.

Teachers' and Students' Perception of the Use of Simulators

From the teacher's perspective, online simulations provide a controlled environment in which students can experiment without risk, thereby reinforcing their confidence and sense of safety when later using real laboratory equipment. By observing the progression of virtual activities, instructors can anticipate potential methodological difficulties and adapt instructions before the in-person session, minimizing common errors and optimizing the use of physical resources. Moreover, in contexts with limited equipment, the platform functions as an equitable resource by providing all students with access to comparable experimental experiences, regardless of the instruments available at their institution.

Teachers emphasize that prior use of simulators alleviates part of the operational burden during face-to-face practice, as many handling and interpretation errors are addressed virtually. This allows them to concentrate on students who face greater challenges in understanding concepts, offering more timely and targeted feedback. Rather than supervising every measurement or adjustment, instructors can guide critical discussions, clarify conceptual misunderstandings, and design additional tasks to deepen learning.

Students, in turn, report that the simulations give them the opportunity to freely explore different scenarios, repeat measurements as needed, and become familiar with experimental procedures without the fear of damaging equipment. This pre-practice reduces the anxiety associated with initial contact with physical instruments and encourages a more proactive attitude: students arrive at the lab with clear hypotheses, an understanding of the experimental steps, and greater readiness to analyze results, rather than focusing solely on manipulating the apparatus

Likewise, both teachers and students recognize the didactic contribution of simulations to collaborative learning. The platform fosters teamwork by enabling participants to compare observations and measurement strategies, thereby enriching the learning experience. Students particularly value the instant feedback and access to support materials, such as interactive guides and examples, which reinforce theoretical concepts and help consolidate knowledge prior to hands-on practice.

Taken together, these impressions suggest that the incorporation of simulators not only complements traditional instruction but transforms the learning experience, promoting a more reflective, safe, and participatory environment for both teachers and students.

Improvements and Future Directions

Although the results highlight the pedagogical value of the simulators, several areas for improvement have been identified to enhance their educational impact. First, it is suggested to standardize the instructional guides so that all simulations include both an independent document and an integrated version within the simulator interface. This dual format would facilitate immediate consultation during the virtual practice while ensuring that students have access to clear and consistent instructions across all activities.

Second, it is recommended that all simulators incorporate interactive activities with automatic feedback. Such features would allow students to verify their answers, correct mistakes, and consolidate their understanding before engaging in the face-to-face laboratory session. This kind of immediate feedback not only emulates more realistically the dynamics of a physical laboratory but also fosters self-regulated learning.

Regarding future research, it is proposed to implement these experiences in parallel with a formal mechanics physics course. The goal would be to observe how students' learning evolves throughout the semester by contrasting the impact of simulations with that of hands-on laboratory practices. This design would allow for a more precise evaluation of the extent to which simulators contribute both to conceptual understanding and to the development of experimental skills in a real educational context.

CONCLUSIONS

The implementation of simulators in the STEM educational context demonstrates that digital technologies serve not merely as illustrative support but as catalysts for comprehensive learning. Students did not simply learn the principles of mechanics; they also developed critical thinking skills, the ability to program variations within simulations, and the capacity to analyze quantitative results. This holistic approach better prepares future professionals to address complex challenges by teaching them to integrate science, technology, engineering, and mathematics at each stage of problem-solving.

The results of this study indicate that integrating interactive simulations through GeoGebra and providing accessible delivery via a Wix-based web platform constitutes an effective strategy for strengthening the teaching of classical mechanics in resource-limited contexts. First, GeoGebra's dynamic constructions promote active and reflective learning by enabling students to manipulate variables such as mass, acceleration, and force, and to observe the resulting mathematical and graphical consequences in real time.

Second, the clear organization of content into distinct sections–theory, guide, simulation, and references–combined with Wix's intuitive site navigation, facilitates the design of coherent and autonomous learning experiences. The inclusion of feedback forms demonstrates a high level of usability and acceptance among users, suggesting that this model can be scaled and adapted to other areas of physics education.

Moreover, GeoGebra's flexibility to model phenomena in optics, solenoid dynamics, and other mechanical systems, together with Wix's capacity to integrate and disseminate these resources, underscores the value of digital technologies as partners in the construction of scientific knowledge.

Finally, although these tools cannot fully replace the experience of a physical laboratory, they offer a viable alternative for institutions with limited infrastructure by reducing costs and implementation times. They can also serve as a preparatory guide for institutions that do have physical equipment. Future work should include evaluating the platform's impact with larger and more diverse samples, incorporating qualitative analyses of user interaction, and exploring the integration of artificial intelligence to personalize learning paths.

The combination of GeoGebra and Wix demonstrates its potential not only to enrich the teaching of mechanics but also to promote innovative pedagogical methodologies that recognize technology as an active partner in the educational process.

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AI statement: The authors stated that generative AI tools were used exclusively to assist with language editing and grammar improvement. All scientific content, analysis, figures, and conclusions were developed by the authors, who assume full responsibility for the manuscript.

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