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PHET Simulators as an alternative for Physics laboratories when teaching the uniformly varied rectilinear movement

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RESUMEN

El propósito principal de esta investigación es analizar y sustentar la incorporación de los simuladores interactivos de PhET Interactive Simulations como una estrategia didáctica innovadora y viable frente a los laboratorios físicos tradicionales, con el fin de fortalecer la enseñanza–aprendizaje del Movimiento Rectilíneo Uniformemente Variado (MRUV). Este tipo de movimiento se caracteriza por desarrollarse en línea recta con aceleración constante, lo que implica una variación uniforme de la velocidad en el tiempo; sus ecuaciones permiten determinar posición, velocidad y aceleración, siendo fundamentales en la física escolar. El estudio se desarrolla con estudiantes de primer año de bachillerato de la Unidad Educativa Pueblo Nuevo y busca comprobar si el uso de herramientas tecnológicas digitales favorece la comprensión teórica y práctica del MRUV. La investigación parte del reconocimiento de limitaciones presentes en el aula, especialmente en infraestructura y recursos experimentales, por lo que propone aprovechar simuladores digitales para promover un aprendizaje significativo, dinámico y de fácil acceso. Asimismo, se examina la efectividad pedagógica de los simuladores como recursos accesibles, interactivos y funcionales, capaces de potenciar habilidades cognitivas como la observación, la predicción y el análisis crítico. El estudio posee relevancia académica y social al plantear una solución práctica ante las carencias institucionales y al fomentar la integración de tecnologías educativas acordes con las demandas actuales. Para su validación se emplean métodos como el análisis–síntesis, la observación científica y la aplicación de encuestas, con el objetivo de determinar la eficacia real de estas herramientas en el proceso educativo.

ABSTRACT

The main purpose of this research is to analyze and support the incorporation of PhET Interactive Simulations' interactive simulators as an innovative and viable teaching strategy compared to traditional physics laboratories, in order to strengthen the teaching and learning of Uniformly Accelerated Rectilinear Motion (UARM). This type of motion is characterized by motion in a straight line with constant acceleration, implying a uniform change in velocity over time; its equations allow determination of position, velocity, and acceleration, making them fundamental in school physics. The study is being conducted with first-year high school students at the Pueblo Nuevo Educational Unit and seeks to verify whether the use of digital technological tools

promotes the theoretical and practical understanding of UARM. The research stems from recognition of limitations in the classroom, particularly in infrastructure and experimental resources, and therefore proposes leveraging digital simulators to promote meaningful, dynamic, and easily accessible learning. Furthermore, the pedagogical effectiveness of the simulators is examined in terms of their accessibility, interactivity, and functionality, which enhance cognitive skills such as observation, prediction, and critical analysis. This study is academically and socially relevant because it proposes a practical solution to institutional shortcomings and promotes the integration of educational technologies that meet current demands. Its validation employs methods such as analysis and synthesis, scientific observation, and surveys to determine the actual effectiveness of these tools in the educational process.

INTRODUCTION

Teaching physics in high school presents some challenges due to the subject's complexity and the lack of infrastructure and labs for experimenting with different phenomena. In the case of MRUV, it is necessary to link theory and practical experience so that students gain a broad appreciation of the technique and experiential knowledge. In several educational institutions, such as the *Unidad Educativa Pueblo Nuevo*, there are no physics laboratories because it goes beyond the budget; there is also a lack of appropriate equipment or space for this type of activity. Given this situation, the PhET interactive simulators are an innovative educational tool that, to some extent, helps compensate for the absence of physics laboratories.

This resource, developed by the University of Colorado at Boulder, enables students and teachers to interact with simulations across physics, chemistry, biology, mathematics, and earth sciences (University of Colorado at Boulder, 2008).

These simulations are designed to promote active learning and the visual and practical exploration of scientific concepts.

Through dynamic, easily controlled graphical representations of physical phenomena, these platforms allow users to virtually experience, explore, and analyze MRUV behavior in a controlled environment. This technology, combined with theory, allows us to go beyond traditional limitations in education, such as the need for laboratory materials or the difficulty of reproducing certain experiments due to safety or time constraints. Furthermore, it offers comprehensive preparation tailored to students' needs and enables us to assess their progress amid academic challenges.

(Domich, 2021) It is noted that the implementation of digital resources as a didactic means, oriented toward advanced-level students, constitutes an innovative strategy to improve the quality of training, foster reflexive approaches, and promote more participatory activities. In recent years, technological resources have taken a prominent role in physics teaching and learning; they enable students to engage in interactive tasks when physics laboratories are unavailable. A remarkable example is the PhET simulator, designed by Carl Wiemann in 2012. (Chávez Farfán, 2023).

The goal, therefore, is to incorporate an innovation or alternative into the teaching process, on the premise that such a transformation may progressively become part of the general education model. According to some studies conducted in coordination with CEPAL and the United Nations, educational institutions in 17 Latin American and Caribbean countries have digital infrastructure that reflects problems with access, insufficient teacher training programs, and inadequate resources. While some countries have pushed for training in information and communication technologies (ICTs), they often fail to address the real needs of each context.

In this context, this research paper provides the foundation for implementing a physical-virtual laboratory to increase students' motivation and strengthen their understanding of phenomena such as uniform linear motion at the Unidad Educativa Pueblo Nuevo. It also considers its progressive integration into the current education system, aiming to enhance the quality of the formative process and align it with contemporary didactic strategies grounded in digital resources.

RESEARCH QUESTION

How does the use of the PHET simulators influence teaching and understanding uniform linear motion in comparison with traditional physical laboratories for middle school students learning physics?

Teaching and learning uniform linear motion refers to a type of motion in which an object moves in a straight line with constant acceleration, implying that speed changes uniformly over time (Barragán, 2018). These concepts are presented within a cinematic frame, through examples and exercises that show their application in real contexts. Furthermore, a collaborative approach and the integration of technologies through online platforms for physics experimental reports are promoted.

In this context, it is necessary to incorporate digital resources and interactive tools that improve the teaching and learning experience. (Rojas, 2023).

The scholar system has undergone significant changes in recent years due to advances in technological resources.

Furthermore, interactivity is understood as the ability of kids to play a dynamic, formative role, enabling direct participation, engagement with the learning content, collaboration with their peers, and constant feedback.

The MRUV is characterized by the linear motion of an object under constant acceleration. Equations associated with this type of motion are fundamental in physics because they allow us to describe a body's position, speed, and acceleration over time. Among their most remarkable characteristics are the adaptation of resources to individual needs, the ability to access information in linear form, and the integration of varied media, such as videos, images, and texts, to enrich the educational experience. (Ceron, 2023)

Instruments

Didactic resources for cooperation promote communication between teachers and students and enhance collaborative work among students. We can mention organizational and content diffusion, evaluation application, and monitoring of academic advancement among their benefits. This is a possible opportunity enabled by learning management systems, videoconference platforms, and debate forums.

The didactic interactive material integrates practical activities with multimedia components such as images, videos, and simulations, generating a more active and immersive teaching experience. These resources allow students to explore concepts through practical and visual experiences, supporting clearer comprehension and better knowledge retention. Endara et al., 2023).

Table 1

Operationalization of variables and categories

Variables	Conceptual Definition	Operational Definition	Dimensions	Indicators	Measurement scale
Independent Variable: Use of PHET simulators.	Virtual simulators have gained widespread popularity because they allow students to conduct experiments when physics laboratories are unavailable. A remarkable example is the PhET simulator, developed by Carl Wieman in 2012, which provides virtual resources in real time. (Chávez Farfán, 2023)	The independent variable will be measured through a report on the practice of virtual laboratories.	Impact on the comprehension of the MRUV. Students' perception. Integration in teaching.	Generate the necessity of use in activities. Level of comprehension before and after the use of the simulator. Level of acceptance and motivation with the use of the simulator.	**Receive a guide for the realization of a virtual laboratory report.**
Dependent Variable. Level of learning of the rectilinear uniform movement.	Reading consists of decoding words, understanding their individual and contextual meanings, and linking information within the text to the reader's previous knowledge. (Berry et al., 2013, p. 3)	The dependent variable will be measured through the observational technique, not by the participant, using a structured questionnaire with Likert-scale items.	Interpretation of rectilinear uniform varied movement. Ability to apply equations in exercises. Analysis ability.	Capacity for understanding the movement. Inference and critical deduction of the phenomenon. Flexibility in the interpretation of the varied exercises. Understanding of physical phenomena. Coherence when comparing results. Analysis of mistakes obtained manually and the results.	**Survey quantitative scale of results.**

Note. Table 1 presents a description of the variables, including their conceptual and operational meanings, corresponding dimensions and indicators, and the measurement method employed.

Research approach

This study emIt employs quantitative and qualitative approaches to collect objective data that enable the identification of the benefits and impact of using PhET Interactive Simulations for learning rectilinear motion and uniformly varied motion in Physics. This approach is based on the methodological criteria exposed by Roberto Hernández Sampieri (2018).

The approach, distinguished by its precision and objectivity, will enable the collection of clear, systematic data, thereby reinforcing the strength and validity of the conclusions. To evaluate the impact of the PHET simulator and support the conclusions of the contribution to the educational process, a descriptive and inferential statistical study will be conducted. (Romero Urréa, 2022)

Development of digital media activities

Figure 4
Module Interface Session 1

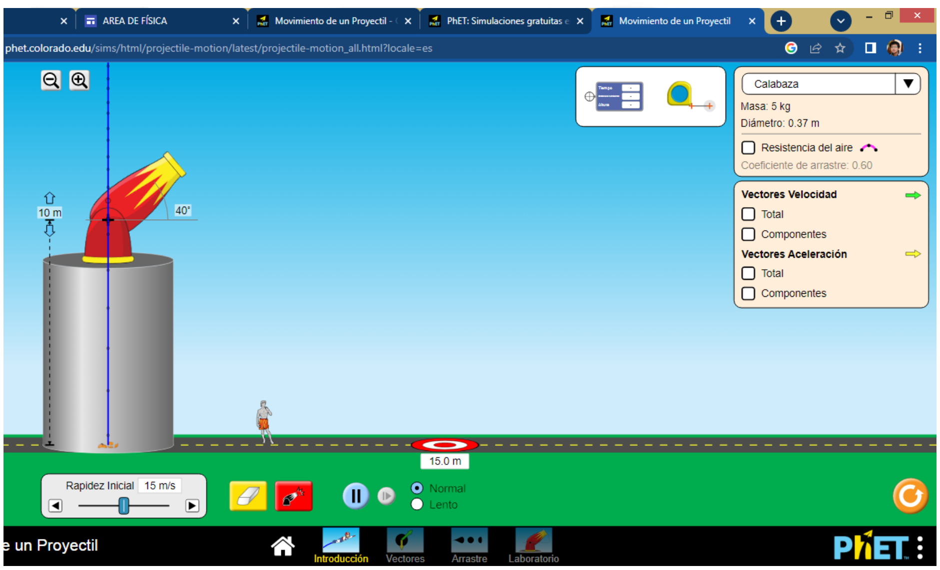
Source: https://sites.google.com/view/sites0area0de0fisica/inicio

Session 1

This first session discusses the theoretical foundations of Uniformly Accelerated Rectilinear Motion (UARM) and its relevance to the analysis of dynamic phenomena in various fields of study. Although it has its origins in physics, it is useful for understanding subjects such as economics, since UARM allows the interpretation of models in which variables are expressed as functions of time. Through an interactive multimedia resource, the student is guided through a conceptual presentation to facilitate familiarity with concepts such as acceleration, speed, and movement. This theoretical foundation prepares the participant to address the simulations to be developed using the simulator, based on sound criteria.

Figure 5

Familiarization of the online simulator (PhET)

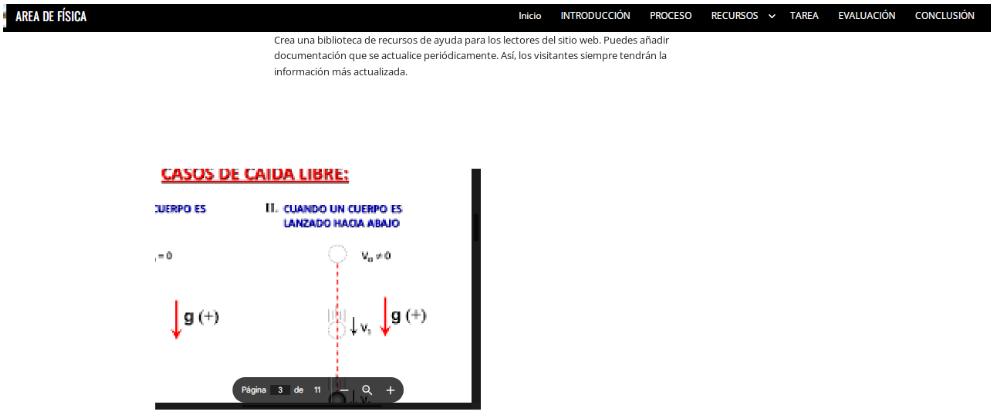


Note: *Interface recognition stage and data manipulation tools*

After that, an exploratory activity using the PhET simulator is proposed. Through this activity, different scenarios involving vertical motion under the influence of gravity are presented. The student modifies parameters such as initial height, object type, and gravitational acceleration. The goal is to observe the variations in fall trajectory and duration**.** Through these interactions, not only are theory and practice connected, but analytical abilities applicable to constantly changing economic phenomena are also strengthened. When recording information developed by the simulator, the student begins to practice systematic data collection, which will allow them to establish quantitative relationships among the variables.

Figure 6

Session 2



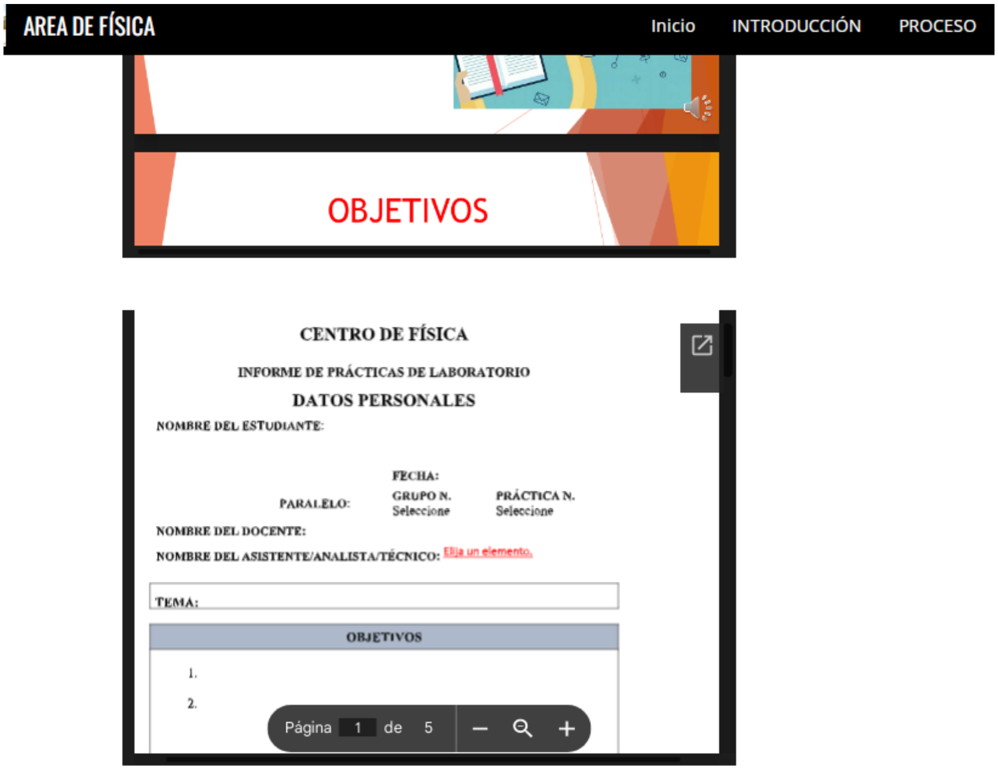
Note: *Revision stage*

In **Session 2**,

The second section begins with a review of prior material to reinforce learning and prepare students for the workshop's practical section.

In this stage, a simulation of a freely falling object is proposed, using initial conditions that the student must determine himself. This practice demands precision both in the design of the experiment and in the collection of data. This exercise aims to develop the ability to abstract real situations and represent them as models for quantitative analysis.

Figure 7 *Session 2*



Note: *data collection for simulation.*

During the simulation, the student records the values of time, speed, and position at successive instants along the trajectory. Posteriorly, these pieces of information are used to elaborate tables and graphics that represent how variables change along the experiment. This stage is ideal for systematically resolving UARM problems, establishing connections between the equations and the observed behavior.

Figure 8

Aplication

Source: https://sites.google.com/view/sites0area0de0fisica/inicio

Results

Participants expressed their opinions in the usual way, i.e., through the laboratory report describing their experience with the virtual simulators. The surveys showed that most users considered the platform effective at helping them understand complex physics topics. It was noted that the digital technique has the important advantage of enabling repeated experiments and online verification of results, compared with traditional practices.

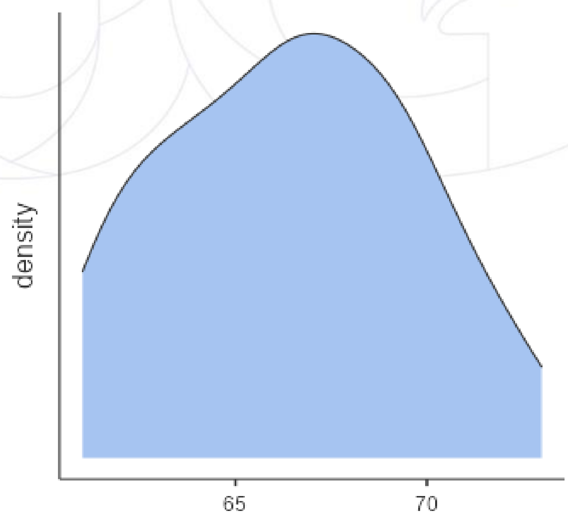
Table 4

Descriptives	
N	80
Lost	0
Average	82.9
Median	82.5
Estándar deviation	4.79
Minimum	74
Maximum	93

Note. *In the taThe analysis of the results of the post-test evaluation, it can be observed (uniformly accelerated rectilinear motion)*

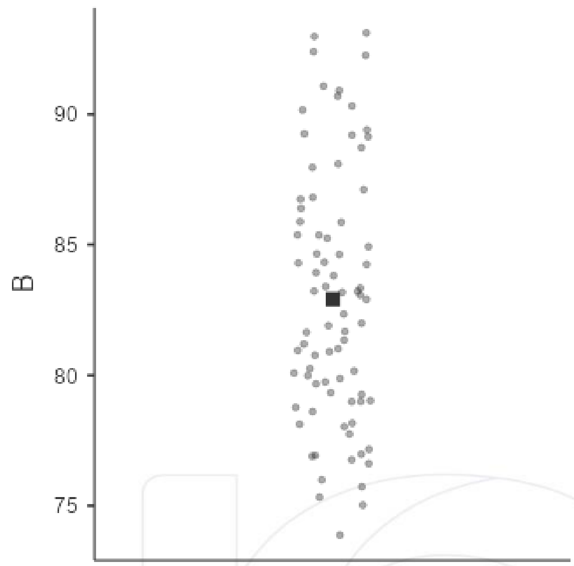
Note. *Own elaboration*

Figure 9



Note: The density plot displays the results from the structured post-test questionnaire.

Figure 10



Note: The scatter plot displays the results from the structured post-test questionnaire.

Participants expressed their opinions as usual, through the lab report describing their experience with virtual simulators. Surveys indicated that most users considered the platform adequate for understanding complex physics topics. It was said that the digital technique offers the advantage of conducting repetitive experiments and comparing results over the network, a capability that differs from traditional lab practices.

Table 4

Statistics	**Pretest (X_1)**	**Posttest (X_2)**	**Difference (X_2 - X_1)**
Average	66.49	82.37	+15.88
Standard deviation	3.19	2.54	2.91*
Minimum	61	77	+16
Maximum	73	89	+16

Note. *Key data for the analysis*
Note. *Own elaboration*

T-Test Results

Hypothesis:

H_0: $\mu_1 = \mu_2$ (There are no differences between pretest and posttest).

H_1: $\mu_1 \neq \mu_2$ (There are significant differences between pretest and posttest).

Table 5

Paİndependent Samples T-Test					
			statistic	**df**	**p**
A	B	Student's t-test	-48.0	79.0	< .001

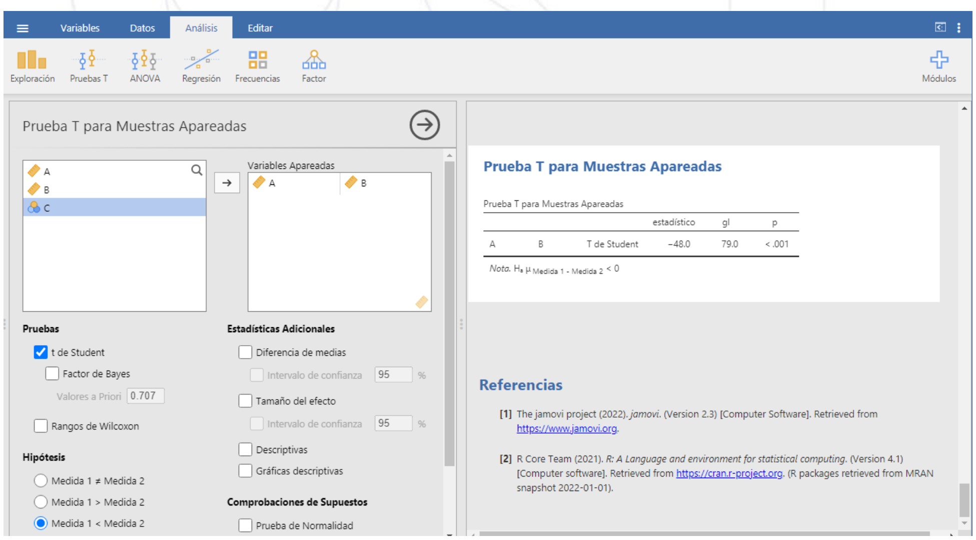
Note. H_a $\mu_{\text{Measure 1 - Measure 2}} < 0$

Note. *Results*
Note. *Own elaboration*

The efficacy of PHET simulators in learning Uniformly Accelerated Rectilinear Motion (UARM) was demonstrated using a related-samples t-test. The null hypothesis proposed that the pretest and posttest results were equal, whereas the alternative hypothesis posited that there were relevant differences after the pedagogical intervention. The data showed that the digital method was clearly superior to traditional teaching methods.

The analysis showed that final grades improved by 15.88 points, representing a 23.9% increase in academic performance. All participants in the analyzed sample, without exception, showed progress in conceptual comprehension. The consistency of these results strengthens the reliability of the conclusions reached.

Figure 11



Note. *The use of the software jamovi to elaborate on research results.*