Towards the Development of Research Skills of Physics Students through the Use of Simulators: A Case Study

Benjamín Maraza-Quispe*, Jorge Luis Torres-Loayza, Grunilda Telma Reymer-Morales, Jose Luis Aguilar-Gonzales, Edwin Wilber Angulo-Silva, and Diego Alonso Huaracha-Condori

***Abstract*—The objective of this research is to evaluate the impact of using the simulators on students' achievement of competencies, such as: Inquire, through scientific methods to build knowledge. The methodology used consisted of qualitative research whose data collection was carried out through an experiment with interactive Physics Educational Technology (PhET) simulators. The experiment was carried out through a simple random sampling of 25 students from a population of 100 students of physics subjects. With this sample, four learning sessions were developed using the PhET interactive simulator, which were implemented in a way that helped the development of skills according to learning indicators oriented to the achievement of the competence, Inquire, through scientific methods to build knowledge. A pretest and a posttest were applied. The results of the study show the benefits of the use of simulators in the teaching-learning processes, contributing to the achievement of the competence inquire, through scientific methods to build knowledge, developing capacities, such as: Problematize situations to inquire, design strategies to inquire, generate and record data or information, analyze data and information, and evaluate and communicate the process and results of their inquiry. In conclusion, 100% of the students develop inquiry competencies through the development of capabilities.**

***Index Terms*—Competences, research, simulators, teaching, learning**

I. Introduction

After the failure of the traditional educational model, information technologies began to gain popularity in society. The Internet is a clear example of this, since it reduced the inequalities of access to information, due to the fact that the huge computer network that composed it freely offered all the knowledge that the users themselves published [1]. As a consequence, the "golden age" of Information Technologies in education began with the new modern or 21st century educational model. The continuous technological development is one of the main drivers for the fulfillment of the Sustainable Development Goals (SDGs), focused on improving education, by allowing students and teachers to access a huge network of knowledge and digital tools, of which the use of simulators stands out. Through the use of simulators in the teaching-learning processes, one of the best ways of learning and teaching is developed [2]. A clear example of this is the use of the PhET Interactive Simulator due to its ease of interaction, allowing users to make changes at the time of performing the activity and receive the results instantly, thus favoring the achievement of better learning expected in the area of Physics [3]. This research highlights the importance of the use of simulators for education, focusing on the development of the physical competence: "To inquire, using scientific methods to build knowledge". The guiding question of the research was: To what extent does the use of simulators allow the achievement of inquiry competencies and skills in students?

Simulation offers the possibility of observing the behavior of individuals under pressure conditions without the company having to bear any additional cost for errors made. Despite the benefits of simulators, their use in business management education is still far from widespread, largely due to the lack of a common applicable methodology, which makes it difficult to implement these educational resources in their curricula. In the field of teaching, simulators make it possible to put into practice the knowledge acquired so far, increasing the added value generated by combining theory and practice, whereas virtual laboratories are computer sites that simulate a learning situation commonly carried out in a physical space called a laboratory. More specifically, virtual laboratories are simulators that model a real laboratory or experiment, run on a computer. They are considered simulators because the equipment, devices and materials needed to run the experiment do not physically exist; however, the modeling of the phenomenon and the components of the simulator allow experiments to be repeated multiple times, with different parameters, until the principles of the system's operation are understood.

In science education, especially in the subject of physics, the development of research skills using simulators has been considered very important since the 19th century [4]. Therefore, a teaching model is developed using the interactive simulator Physics Education Technology (PhET) for the development of the chosen competence in the area of physics. According to Pérez-Higuera's work, The PhET Interactive Simulations project at the University of Colorado Boulder creates free-to-use interactive math and science simulations, PhET simulators are based on extensive educational research and engages students through an intuitive game-like environment, where students learn through exploration and discovery [5], which cover content such as: magnetism, optics, dynamics, matter, among others; which are organized by schooling levels from elementary, middle school, high school and higher education, according to the US educational system [6]. Likewise, PhET

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simulators are developed based on the following principles: encourage scientific research, provide interactivity, make the invisible visible, illustrate mental models and include moving bodies, graphics, data and real-life examples [7]. The interactive simulator PhET is a free online platform with more than 150 simulators oriented to the areas of science and mathematics, from which we can alter different variables to understand the behavior of phenomena in our world. Therefore, it is widely used in the educational field for the teaching-learning process, in order to develop new skills in students.

The functionality of the PhET interactive simulator, investigated by Rodríguez-Abril *et al.* [8], is discussed below:

- It allows the student to build and test models of reaction-controlled closed systems.
- It allows the construction of open dynamic models of systems of phenomena.
- It allows you to manipulate variables and check their results.

PhET offers fun, free, interactive and research-based scientific and mathematical simulations. The designers have thoroughly tested and evaluated each simulation to ensure its educational effectiveness. This testing includes interviews with students and observation of simulation use in classrooms. The simulations are written in HTML5 (with some legacy simulations in Java) and can be run online or downloaded to the computer. All simulations are open source. Multiple sponsors support the PhET project, allowing these resources to be free to all students and teachers. Very important arguments that allowed us to choose PhET simulators for research development because, as users interact with these tools, they receive immediate feedback on the effect of the changes made. This allows them to investigate cause-effect relationships and answer scientific questions by exploring the simulation.

According to Fuentes and Herrera's work, the educational environment generated by the use of simulations, allows experimentation, obtaining different solutions to problems, enhancing the use of methodologies such as the resolution of problem situations [9]. That is why, in the educational environment, the PhET interactive simulator has a high potential for the development of skills and new learning based on experience through simulation. Moreover, PhET interactive simulators provide a number of advantages and disadvantages that determine their effectiveness in the educational environment; on the one hand, it allows immediate feedback by adjusting magnitudes and measurements on the fly and receiving the effects immediately and visibly, it has an intuitive and fun interface so that users can use the simulators with great ease, and it allows repeating simulations infinite times, without exhausting resources [10]. However, it is necessary to have internet access to be able to access the simulations or download them previously, it is necessary to have technological equipment such as a computer to perform the simulations and they are programmed to be executed by a single person, so it does not allow to be executed by a group. Despite this, their positive properties that generate more benefits and challenges for users stand out much more [11].

The development of Inquiry competencies, through scientific methods to build knowledge, allows students to build their knowledge about the functioning and structure of the natural and artificial world around them, through scientific procedures, reflecting on what they know and how they have come to know it, bringing into play attitudes such as curiosity, wonder, skepticism, among others [12], all involving the procedures or methodologies that are applied to generate more questions, or to try to answer them [7]. In short, this competence helps students to be able to develop and strengthen their inquiry skills, exploring the behavior of our world through the methodologies developed by science, which allowed them to find solutions, provide answers and generate new questions [13]. From this perspective, it is important to consider that scientific methods are mainly based on experimentation, so the student must be able to reflect on the situation to strengthen their own knowledge. To successfully achieve this competence, it is important to recognize in student's certain skills, according to Trujillo-Yaipen's work, "Students develop the skills of: Understanding information, Inquiring and experimenting; acquiring knowledge and attitudes necessary to be retained in everyday life, as well as adopting responsible attitudes towards the development of science and technology" [14]. In this way, by observing, actively exploring and reflecting on their experiences, they learn and are able to modify their future actions.

To develop the competency, inquire through scientific methods to build knowledge, it is important to identify in each student the skills of inquiry, experimentation, comprehension and observation and thus recognize whether a student is apt to develop as a science inquirer [15].

According to Rodríguez-Abril *et al.* [8], one of the digital tools on the Internet is the interactive simulator PhET, which has managed to adapt to the teaching-learning models of educational centers, being included as a strategy for the development of certain skills and competencies, such as "Inquiring, using scientific methods to build knowledge", where with the help of the options and tools offered by the simulator, a student is able to conduct an investigation autonomously or also under the guidance of a teacher, in order to explore the behavior of different phenomena of science [16].

According to Ben-Ouahi *et al.*'s work [17], PhET interactive simulators allow a productive exploration thanks to their controllers to manipulate quite intuitive variables and visual representations even of intuitive abstract concepts, visual representations of abstract concepts and immediate feedback through visual and animated changes, this allows them to analyze cause-effect relationships and answer scientific questions through the exploration of the simulation [7]. They also allowed to awaken interest, curiosity and motivation to move from a traditional expository lecture methodology to a constructive and interesting one in which students are able to build their knowledge to become inquiring learners. Undoubtedly, the PhET interactive simulator provides a useful environment for the experimentation of different real-world phenomena through simulations that develop new skills in the learner, as well as allowing a teacher to guide learners through the learning process and thus identify progress in relation to the course competencies.

According to Trujillo-Yaipen's work [14], with PhET interactive simulators we can experiment with terrestrial gravity, with parabolic shots, with radio signals and electromagnetic effects, build simple electrical circuits, represent graphic equations, experiment with laser signals; among other possibilities, thanks to all the options that allow us to choose the PhET interactive simulator, we can start with the development of scientific skills to: explore facts and phenomena; analyze problems; observe, collect and organize relevant information; use different methods of analysis; evaluate methods; share results scientific skills to: explore facts and phenomena [18], being of great benefit for the development of the competency: Inquire, using scientific methods to build knowledge.

II. Methodology

The methodology used follows a qualitative experimental approach in which learning sessions were developed with 25 students using PhET interactive simulators, the sessions were prepared for the achievement of the competency: Inquire through scientific methods to obtain knowledge, standardized tests were applied at the beginning and at the end of the experimentation to make comparisons by skills achieved.

A. Research Objectives

The objective of this research is to evaluate the impact of the use of simulators in the development of inquiry skills, using a scientific approach to allow students to build knowledge in physics.

B. Research Hypotheses

The use of interactive simulators in the teaching process helps to develop competencies. "They inquire, using scientific methods to construct knowledge" in students taking Physics.

C. Research Variables

1) Independent variable

Interactive simulator

2) Dependent variable

Competency: Inquires, using scientific methods to construct knowledge.

3) Controlled variable

Evaluation method: It is included as a controlled variable because the evaluation method influences the dependent variable.

- Number of learners: The number of learners is considered a controlled variable because it depends on the number of learners using the simulator, the achievement of learning competencies.
- Time of use of the PhET interactive simulator is considered a controlled variable because it influences the achievement of the dependent variable.

D. Population and Sample

The population consisted of 100 fourth-year Physics students, from which 25 students were selected by simple random sampling. With this sample, four learning sessions were developed using the PhET interactive simulator. As shown in Table I.

TABLE I: Sample and Periods of the PhET Interactive Simulator Application

Interactive simulator	
PhET	
Duration of the experimentation	
3 weeks	
Students	
Number of students	**Average age**
25	15
Number of teachers	
1	
Sessions	
Sessions	**Evaluations**
4	4
Duration of each session	
60 minutes	

E. Methodological Design

The methodological design presented is a learning model; the stages of the learning model can be seen in Table II.

F. Data Collection Instruments

The data collection is divided into two moments, see data collected here. In the first group, three knowledge assessments and exercises were applied to observe the student's learning process, evaluated in the vigesimal system. Being the first assessment designed by Tsokos [19] in his book Physics for the IB Diploma, Sixth Edition, as for the second and third assessment consisted of a collection of physics exams of the IB program type test 1. In the second group, an inquiry type test prescribed to measure the level of performance in the competence "They inquire through scientific methods to construct knowledge" was applied according to the capabilities designed in the pedagogical model of the subject of Physics [20].

TABLE II: Activity Planning

Session number	Description of activities carried out	Performance indicators	Capacities
Session 1 (Pre-evaluation)	The methodology, objectives and schedule of the experimental sessions are presented.	Level of understanding for the presentation of the methodology, objectives and dates on which the activities were carried out. Degree of understanding of the subject matter Diagnostic assessment to determine prerequisites	Problematizes situations in order to make enquiries
	The topics to be developed in the learning sessions are presented so that students can begin with an independent inquiry.		
	A pre-test is applied to the students.		
Session 2 (theory)	They explain how the proposed theme "free fall of bodies" applies to our life and the phenomena of the world.	Asks questions about natural facts and phenomena, interprets situations and formulates hypotheses	
	Explain the theoretical basis of free fall, using their respective formulas.		
	Perform free-fall exercises on the blackboard as an example for students to understand the procedures.	Propose activities to build a procedure, select materials, instruments and information to test or disprove hypotheses.	Devises strategies for enquiry
	Propose exercises on the board for students to solve in their notebooks and on the board as volunteers.		

Session 3 (Practical)	They present and explain the operation of the PhET interactive simulator.	Obtain, organize and record reliable data according to variables, using instruments and various techniques to test or disprove hypotheses.	Generates and records data or information
	Enter the free fall section of the PhET simulator and explain each simulation tool, suggesting that students begin by interacting with it.		
	Present a free fall problem and record the variables in the simulator.		
	Modify the variables in the simulation to recognize the effects it generates.	Interpret the data obtained in the enquiry, contrast it with the hypotheses and information related to the problem in order to draw conclusions that prove or disprove the hypotheses.	Analyses data and information
	They take raw data from the effects observed in the simulation.		
	Tabulate and graph in a spreadsheet the data obtained in the simulator, in order to find the final answer to the proposed problem.		
Session 4 (Evaluation)	A post-test is developed in order to contrast it with the pre-test	Identify and publicize the technical difficulties and knowledge gained in order to question the degree of satisfaction the answer gives to the research question.	Evaluates and communicates the process and results of its enquiry

III. Raw Data Processing and Analysis

A. *Section 1: Process Evaluations*

In order to analyze each student's progress in detail, three process evaluations were developed to determine each student's level of understanding of the subject. The following results were obtained.

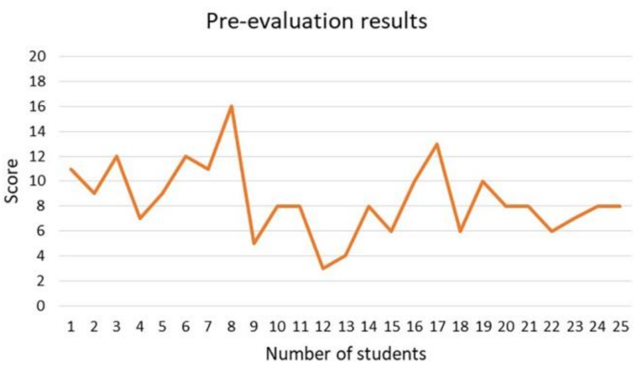

Fig. 1. Results — Pre-evaluation.

According to Fig. 1, it is observed that the highest percentage of the results are scores below 11, considered at the starting level. This indicates that, students do not have much knowledge of the subject, which is understandable when measuring their initial knowledge prior to their explanation, intended to serve as a starting point for adjusting functions in simulation environments to help students arrive at specific simulation setups as needed [21].

B. *Results of the First Evaluation*

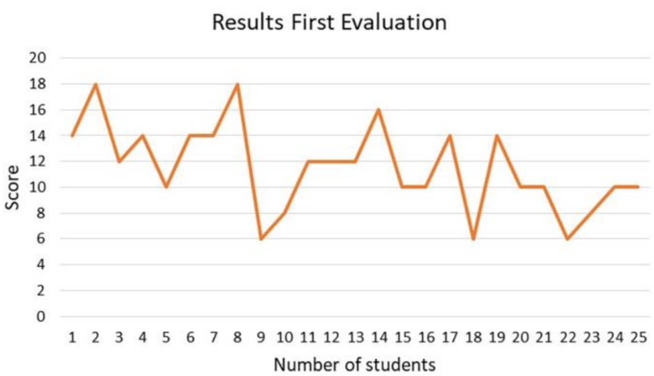

Fig. 2. Results — First evaluation.

According to Fig. 2, it can be observed that the scores were better than their predecessors, however, it was a minimal difference. The same situation was experienced in his research [7], when he identified difficulties in understanding and applying mathematically the definition of physical concepts, giving as a solution the PhET simulator, concluding that the theory is a challenge for the students' learning and another more interactive methodology that integrates theory and practice in the same system is necessary.

C. *Results of the Second Evaluation*

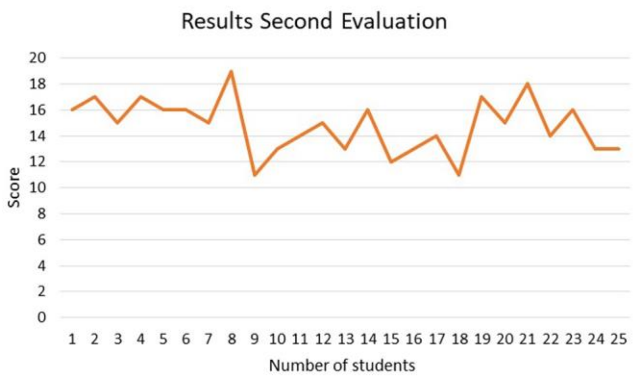

Fig. 3. Results — Second evaluation.

According to Fig. 3, it is observed that the results were more positive with 100% passing grades, demonstrating the effectiveness of the PhET simulator for the understanding of students in the area of Physics, as described by PhET Interactive Simulator, "Interactive simulations through PhET transfer the role of interacting with the student, which enhances their learning", making it a great educational ally for the teaching-learning process being able to experiment without the need for a physical laboratory [22].

D. *Comparison of Results*

According to Fig. 4, it can be observed that in relation to the pre-evaluation of both methodologies, both theoretical and practical using the PhET interactive simulator, there was an improvement in the students' understanding. However, after the practice with the simulator this improvement was more noticeable, reaching the highest scores. Demonstrating the difficulty of students to learn from the traditional methodology, as well as the benefits in their learning through other more interactive methodologies.

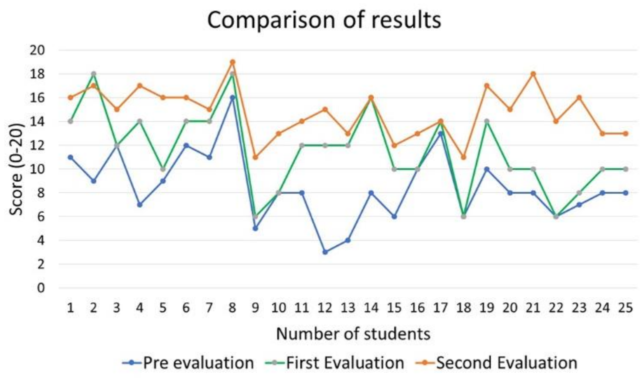

Fig. 4. Comparison of results.

E. Capacity-Based Analysis of the Final Evaluation

In order to analyze the level of performance in the competency “They inquire using scientific methods to construct knowledge”, the final evaluation was developed, consisting of a research-type test. The following results were obtained:

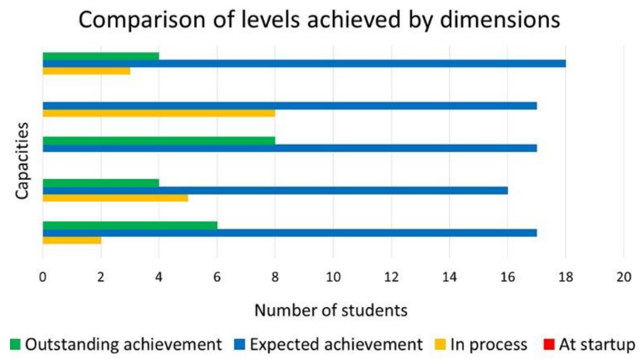

Fig. 5. Comparison of levels by capacity.

According to Fig. 5, 68% of the students reached the expected achievement, 24% reached an outstanding achievement and only a small group of 8% is in process. This means that the students do not have many difficulties in formulating research questions and formulating hypotheses with scientific knowledge, although they still have difficulties in recognizing the variables under investigation and establishing a relationship between them.

Capacity 2: Devises strategies for enquiry, represents the methodology to be developed in a research project and according to Fig. 5 it is observed that 64% are in expected achievement, 16% in outstanding achievement and the number of students in process increased to 20%. This means that students have more difficulties in basing the research objectives, however, it is easy for them to recognize the materials to be used and the procedures to be carried out to answer the research question.

Capacity 3: Generates and records data or information, which consists of obtaining the raw data for an investigation, and according to Fig. 5 an astonishing 32% are in outstanding achievement, the rest being in expected achievement. This means that the simulator gives students the facility to collect qualitative and quantitative data, to manipulate the variables freely and immediately observe the effects occurred, as well as the ability to organize the data in tables and graphs.

Capacity 4: Analyses data and information, identifies the student’s ability to analyze the data obtained and according to Fig. 5, the situation is more worrying, with a percentage of 32% in process and the rest in expected achievement, with no student reaching outstanding achievement. This means that students have more difficulties in establishing a relationship between the data obtained, comparing and contrasting the information to find a result that refutes their hypothesis and draw balanced conclusions.

Capacity 5: Evaluates and communicates the process and results of its enquiry, shows the students’ ability to communicate the results of their research in a clear and orderly manner, where, according to Fig. 5 a high percentage of 72% is in expected achievement, 16% in outstanding achievement and 12% in process. This means that the students have good writing and communication skills through virtual or face-to-face means, independent of the PhET simulator, given that this is not intended for this purpose.

In summary, it can be seen that the best student performance was in capacity 3, since “students receive immediate feedback on the changes they make to the software” [7]. This allows students to manipulate the variables of the simulator with freedom, managing to recognize qualitative and quantitative data more easily. On the other hand, the lowest results were in capacity 4, due to the fact that “physics has many abstract concepts that students cannot easily understand” [23], which makes it difficult to analyze the data because they do not recognize the relationship between them.

F. Competence Assessment

The evaluation of developmental competencies based on the learning achievement scale for regular basic education proposed by the Ministry of Education [12]. As can be seen in Table III.

TABLE III: RATING SCALE LEVEL

Rating	Achievements	Description
20–18	Outstanding achievement	When the student evidences the achievement of the expected learning, even demonstrating a solvent and very satisfactory management in all the proposed tasks.
17–14	Expected achievement	When the student evidences the achievement of the expected learning in the programmed time.
13–11	In process	When the student is on the way to achieve the expected learning, for which he/she requires accompaniment during a reasonable time to achieve it.
10–00	At startup	When the student is beginning to develop the expected learning or evidences difficulties for the development of these and needs more time of accompaniment and intervention from the teacher according to his/her pace and learning style.

Fig. 6 shows the performance level of each student in the competency: Investigates through scientific methods to construct knowledge, taking into account the total average of the scores achieved in each competency. From which it can be observed that no student is in the beginning, only one student is in process, 21 students are in expected achievement and three students are in outstanding achievement. This demonstrates the potential of the simulator to improve the development of skills for the development of competencies, being able to produce their own knowledge, through inquiry and experimentation, using scientific methods. Causing in the students an increase in the levels of cognitive load producing a greater storage of information reflected in the improvement of learning [24].

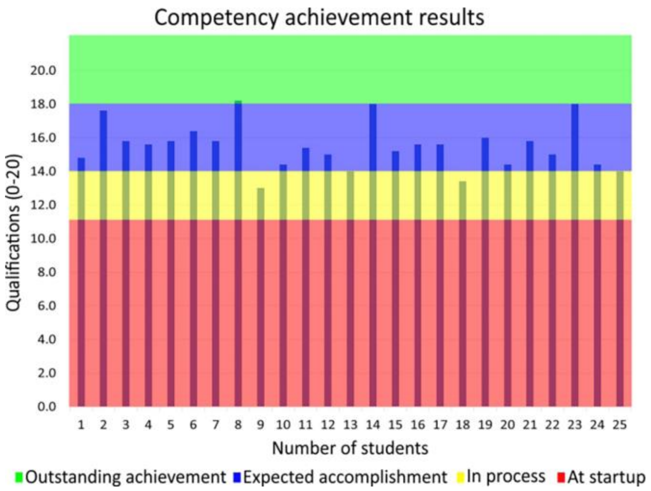

Fig. 6. Evaluation of the PhET interactive simulator.

G. Validation of the Hypothesis

Next, we developed a set of statistical procedures that allowed us to determine whether the research results are the product of random or real effects, in order to validate the hypothesis, put forward at the beginning of the methodology, as shown in Table IV.

TABLE IV: VALIDATION OF THE HYPOTHESIS

Hypothesis	Parameter	Description
Null Hypothesis (HO)	$P > 0.05$	The application of the PhET interactive simulator does not contribute to the development of the competence “Inquire through scientific methods to construct knowledge” in students of physics.
Alternative Hypothesis (AH)	$P < 0.05$	The application of the PhET interactive simulator contributes to the development of the competence “Inquire through scientific methods to construct knowledge” in students of physics.
Alpha		0.05

TABLE V: T-TEST —VALIDATION OF HYPOTHESIS

Measurements	Pre-evaluation	Final evaluation
Media	8.52	15.488
Variance	8.593333333	1.89693333
Remarks	25	25
Pearson correlation coefficient	0.502132461	-
Hypothetical difference in means	0	-
Degrees of freedom		-
Statistic t	−13.73357567	-
$P(T<=t)$ one tail	0.000000000000364	-
Critical value of t (one-tailed)	1.71088208	-
$P(T<=t)$ two-tailed	0.000000000000729	-
Critical value of t (two-tailed)	2.063898562	-
$P < 0.05$		

According to Table V, the alternative hypothesis of the research was validated, which states that the application of the interactive simulator PhET contributes to the development of the competence “To inquire, using scientific methods to construct knowledge” in the students of the physics course.

IV. DISCUSSION

In educational learning processes a simulation requires the student to develop skills at the levels of: application, analysis and synthesis; which involve decision making, evaluation of alternatives and results to re-evaluate the decisions made [25]. This defines simulators as an excellent educational strategy for the learning process in students in different fields and subjects through practice and instant feedback. However, the pedagogical model it manages does not fully promote the development of soft skills and even encourages sedentary lifestyles. However, through experimentation, it has been determined that the use of PhET simulators allows the development of collaborative and interactive work

The use of PhET interactive simulators is part of the globalization process, through technology, creating digital environments to unite the whole world without geographical limits. Therefore, any expression of digital media is part of our culture and should be part of the training of people in the 21st century [26]. Likewise, in the research developed, the results show the achievement of inquiry competencies so that the student can develop in a globalized world.

A characteristic that all simulators possess is their ability to protect their users in situations that pose a risk in real life, transforming reality into a digital world free of dangers, as stated by Contreras and Carreño, they eliminate risks that arise in the interaction with reality for both students and devices, allowing them to focus on the aspect of reality to be studied [27] (p. 109). This provides a safe environment for users and allows them to interact with their features freely without the need to worry about post effects, in order to enhance the user experience within the simulator.

According to Ouahi *et al.*’s work [17], it is necessary to propose standards in terms of learning behavior indicators to be analyzed in In Virtual Learning Environments in order to develop better predictions to optimize the teaching-learning processes (p. 147). They also have the role of guiding students through the advantages and disadvantages of using these digital tools, as well as establishing control parameters to reduce the negative effects on students [22].

Responsibility in students is represented through digital citizenship with the use they make of the simulators, according to Gelves *et al.*’s work [28], Students use the simulators independently and it is necessary that they make them useful for their study (p. 31). Therefore, the responsible and measured use of the simulator is essential to ensure optimal learning that does not sometimes have adverse effects on students that are sometimes addictive, as well as the acquisition of simulators respecting the intellectual probity of the creators of the software [29].

Virtual learning environments for educational use represent a challenge for their developers, since they need to meet high standards to ensure their reliability [30]. In particular, the simulator has to present accurate and up-to-date data on the events of its platform, as well as an intuitive interface and a good functioning of all its applications. It also has to occupy a minimum of resources to be accessible on different processors in order to reduce the digital divide [31].

Thus, demonstrating the positive effects of the use of the PhET interactive simulator, which has successfully demonstrated its great potential in education for teaching this type of subjects, given that, virtual laboratories can lead students to plan and perform experiments [32], which greatly favors their own knowledge production based on the students' experience.

Simulation programs also favor transfer, because they work with an operability close to everyday life. Students have access to situations similar to those of their future professional performance and reconstruct with the teacher the difficulties that arise in the problem-solving process [33]. The results of the research developed also help to represent and solve problems of real and everyday life situations of students [34].

V. CONCLUSIONS

The use of simulators contributes to the development of the competency that students taking physics subjects to build knowledge through scientific inquiry, since a significant improvement was demonstrated in the results of the research. The results obtained proved that, with 100% of the students improving the achievement of the competence and different skills such as: Problematize situations to inquire, design strategies to inquire, generate and record data or information, analyze data and information, and evaluate and communicate the process and results of the inquiry.

Great progress was identified in the development of inquiry skills. As a result, there are three students at the outstanding performance level, 21 students at the expected performance level and only one student in the learning process.

Educators have the responsibility to adapt to the use of new technologies, to use them as didactic methods of teaching in a digitalized society, students have the responsibility to use the simulator in an appropriate way for their learning, and finally, software providers have to provide reliability and security to their users with the information given and received.

The impacts of the research developed produce in the educational aspect the reduction of the digital gap and promotes equal access, improving the understanding of the processes, optimizing learning, another ethical impact in the environmental aspect is the reduction of the use of paper avoiding the felling of trees and as for the economic impacts can promote entrepreneurship through the use of simulators, improving the economy of the population.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest in relation to the research carried out.

AUTHOR CONTRIBUTIONS

Benjamín Maraza Quispe implemented the methodological design, Jorge Luis Torres Loayza reviewed the background, Grunilda Telma Reymer Morales performed the statistical analysis, Jose Luis Aguilar Gonzales analyzed the data, Edwin Wilber Angulo Silva implemented the discussion, and Diego Alonso Huaracha Condori contributed the conclusions and recommendations.

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