Exploring the Intersection of Innovative Strategies: Effects of Integrating Virtual Simulators and Selfregulation on Scientific Reasoning

Walter Manuel Trujillo Yaipen, Magister[1],
[1]Universidad Tecnológica del Perú, Lima, wtrujillo@unprg.edu.pe

***Abstract*– The purpose of this research is to assess the impact of implementing virtual simulators on students' mathematics learning. The methodology adopted is quasi-experimental, with a design comprising pre- and post-intervention tests in two groups: one experimental and one control. The sample consisted of 62 students, divided equally into two groups of 31 each.**

The results of the pretest indicate that, in the "Initiation" category (scores from 0 to 10), 77% of the Experimental Group and 61% of the Control Group were in this phase. In the "Process" category (scores from 11 to 13), 23% of the Experimental Group and 29% of the Control Group achieved these scores. Regarding the "Achieved" category (scores from 14 to 17), no student in the Experimental Group reached this phase, while 10% of the Control Group did. No student in either group reached the "Outstanding" category (scores from 18 to 20).

Furthermore, the study included the use of the Mann-Whitney test to examine the difference between the experimental and control groups in terms of their performance on the test.

Keywords-- Simuladores virtuales, Aprendizaje de matemáticas, Estudiantes de quinto año", Hipótesis nula y alternativa

I. Introduction

The research on mathematics education is on a trajectory of continuous expansion, dynamically confronting present challenges that demand the adoption of innovative strategies backed by solid research and fresh perspectives. In this context, the study delves into the intersection of two pioneering approaches: the integration of virtual simulators and the application of self-regulation techniques, thoroughly exploring their influence on the development of scientific reasoning among students.

The work of Alfieri et al. [1] emerges as a fundamental turning point by questioning traditional practices and advocating for a broader, more holistic approach to the development of scientific skills. On the other hand, Amsel et al. [2] have highlighted the relevance of metacognition in resolving cognitive conflicts, providing an essential theoretical framework for understanding how these skills can propel scientific reasoning to new frontiers.

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The fundamental purpose of this research is to deepen understanding of how the convergence between virtual simulators and self-regulation can catalyze scientific reasoning, offering new perspectives for both the academic community and educational program designers. The fusion of these strategies not only promises to enrich mathematics education but could also have transcendent applications in various fields of study.

The development of educational technology supports this integrative approach, recognizing the potential of virtual tools to enhance the understanding and application of mathematical concepts. Previous research, such as that conducted by Carrión-Paredes et al. [3], has validated the effectiveness of virtual simulators in other scientific disciplines, laying the groundwork for their application in the mathematical domain.

However, it is essential to understand not only the potential advantages but also the challenges and limitations of this approach. Studies like those of Iriarte Pupo et al. [4] and Trujillo Yaipén et al. [5] provide a detailed analysis of how these tools can influence the acquisition of specific mathematical competencies.

In addition to the educational aspect, it is crucial to consider the broader context in which education is framed. Globalization and technological advancement have radically transformed the way we learn and teach. In this regard, information technologies play a fundamental role in the evolution of the educational system, as evidenced by the studies of Trujillo et al. [6].

In this scenario, mathematics education emerges as a critical field facing significant challenges in the effective transmission of knowledge, especially in disadvantaged communities [7]. The solving of mathematical problems, which demands skills of regularity, equivalence, and change, becomes even more demanding for students lacking access to advanced educational resources [8].

This study aims to address the identified disparity in learning experiences by introducing an innovative strategy focused on the use of virtual simulators as a means to democratize access to high-quality mathematical education.

The main objective is to evaluate the impact of this intervention on the development of problem-solving competencies, shape, motion, and location in secondary school students in environments with limited educational resources.

Existing literature highlights the lack of advanced educational resources in disadvantaged contexts, thus underscoring the crucial importance of this study in bridging this gap and strengthening the mathematical skills of students in underserved areas [7]. Furthermore, the fundamental role of teachers as agents of change in promoting educational equity, especially in resource-limited environments, is emphasized [8].

This research focuses on evaluating the impact of virtual simulators, particularly the Interactive PhET Simulator, on the achievement of competencies in problem-solving, shape, motion, and location in mathematics students in contexts with limited educational resources. It aligns with the overall goal of challenging traditional limitations in mathematics education and promoting an inclusive and accessible approach that maximizes the use of available technologies.

It is encouraging to note that previous research supports the effectiveness of virtual simulators as complementary tools in mathematics education, even in resource-limited environments [4,5,10]. However, significant challenges in global educational equity persist, underscoring the importance of implementing effective pedagogical interventions to address these disparities [11].

A specific challenge is identified in mathematics learning, particularly acute for marginalized populations, whose difficulties are starkly reflected in the pretest results. Faced with this reality, collaboration among teachers, communities, and educational authorities emerges as a critical and unavoidable factor in transcending these obstacles and fostering an inclusive and enriching learning environment. In this context, the present study stands as a beacon of hope, seeking not only to address these challenges but also to open new frontiers in mathematical pedagogy. Through the exploration of innovative strategies, the aspiration is to stimulate not only interest but also a deep understanding of mathematics, even in environments marked by limitations in educational resources.

II. METHODOLOGY

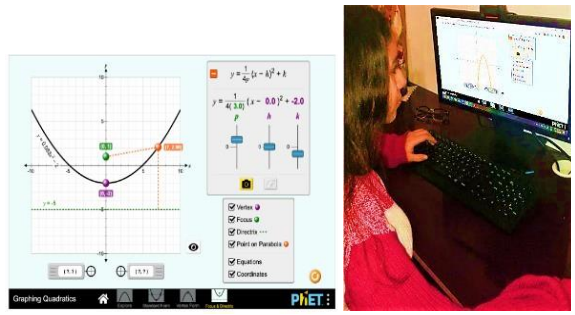
Our research delves into an exciting realm: exploring how the combination of virtual simulators and self-regulation strategies can shape students' scientific thinking. To unravel this puzzle, we embarked on a quasi-experimental approach, a path allowing us to compare two groups of students: one experiencing our innovative amalgamation and another that does not.

a) Scientific Theoretical Foundation of Variables:

a.1) Independent Variable: Virtual Simulators:

Phet virtual simulators are key components in education, facilitating didactic knowledge transfer accurately. This independent variable focuses on the degree of virtualization, highlighting its utility in contexts laden with risks or resource limitations [12].

Fig 1. Application of the "PHET" virtual simulators in the experimental group



Note. The figure depicts the student immersed in the learning process, interacting with Phet virtual simulators on their electronic devices.

a.2) Variable: Learning:

According to the Ministry of Education (Minedu) [13], solving geometric problems involves students interacting with various shapes, movements, and spatial relationships. This process encompasses several aspects, such as accurately describing the position and movement of objects in space, as well as discerning, interpreting, and correlating the characteristics of these objects with both two-dimensional and three-dimensional geometric shapes.

Additionally, it involves the ability to make direct or indirect measurements of different magnitudes, such as area, perimeter, volume, and capacities of objects. Likewise, the importance of creating accurate graphical representations of geometric shapes is highlighted, which is fundamental for designing objects, plans, and models.

In this context, the resolution of problems related to various forms, movements, and spatial orientations is examined in detail. This includes the ability to model objects with specific geometric configurations and the application of effective spatial orientation strategies [13].

b) Type and Research Design:

b.1) Type of Research:

The type of research we conducted falls under the category of applied research. In this type of research, the main objective is to use existing knowledge to address and solve practical problems in the real world. In our case, our study not only aimed to expand the knowledge base in the field of mathematical education but also to offer practical solutions to improve the teaching and learning process in the classroom.

b.2) Research Design:

Our study was based on an experimental approach, specifically adopting a quasi-experimental design. This approach allowed us to assess the impact of our intervention on students' learning rigorously, despite not randomly assigning participants to the experimental and control groups.

c) Population and Study Sample:

Our research focuses on improving the academic performance of students enrolled in a mathematics course, a group composed of a total of 73 students. To ensure that our sample was representative, we carefully selected 62 students, evenly dividing them between two groups: the Experimental Group and the Control Group.

TABLE I
DISTRIBUTION OF STUDENT SAMPLE

Study groups	*Section*	*Number of students*
Experimental group	***A***	***31***
Control group	***B***	***31***
	Total	***62***

Nota This table represents the sample of students in the pre-test phase.

The choice of a convenience sampling method was due to the ease of access to groups of students, facilitated by the fact that the researcher also plays the role of teacher in the selected classrooms. However, it is crucial to highlight that before carrying out any intervention, we meticulously validated our measurement instruments with the help of experts in the relevant field. This ensured the reliability and validity of our data and results.

In our endeavor to improve mathematics learning, we immersed ourselves in the world of virtual simulators. These educational resources are specifically designed to strengthen key mathematical concepts in an interactive and engaging manner. The simulators offer students the opportunity to experience mathematical situations practically, through the manipulation of graphical models and the exploration of different scenarios. In addition to the implementation of virtual simulators, we incorporated self-regulation learning strategies to empower students in actively controlling their learning process. These strategies not only focused on mathematical content but also on the development of metacognitive and self-management skills. Students were guided in defining specific learning goals, effective study planning, constant monitoring of their progress, and reflection on their learning experiences to identify areas for improvement and adjust their study strategies accordingly.

d) Evaluation Instruments:

Our evaluation instruments are essential for measuring the impact of our interventions on student learning. To this end, we designed both pretests and posttests that cover both theoretical concepts and the practical application of mathematics. These assessments allow us not only to assess the initial level of student knowledge before the intervention but also to measure their progress and understanding at the end of the study period.

In addition to these formal assessments, we adopted a more holistic approach by closely observing student participation during virtual simulation sessions. During these activities, we actively recorded the level of engagement and participation of students, providing invaluable information about their degree of involvement and the impact of activities on their learning. In addition to the quantitative data collected through our formal assessments and observation of participation, we also used anecdotal records to capture qualitative aspects of student engagement and participation. These records allow us to gain a deeper understanding of the student experience during simulation activities and provide additional contexts for interpreting the results of our interventions.

e) Data Analysis:

After collecting data, we embarked on a comprehensive statistical analysis using the Mann-Whitney U test. This method is a valuable tool when comparing two independent groups, and the data are not normally distributed, which is common in studies of this kind. To carry out the Mann-Whitney U test, we first ordered all collected data from lowest to highest, combining the data from both groups. Next, we assigned ranks to these data, regardless of which group they belonged to. Then, we calculated the sum of ranks for each group separately. Finally, we used these values to calculate the Mann-Whitney U statistic and determine if there was a significant difference between the two groups in terms of the variables we were analyzing.

This approach allowed us to identify if the observed differences between the experimental and control groups were statistically significant about their scores on the pretests and posttests. By employing the Mann-Whitney U test, we could accurately assess whether the intervention implemented in the experimental group had a significant impact compared to the control group, providing us with a deeper understanding of the effectiveness of our educational strategies.

III. RESULTS:

During the research process, virtual simulators were used to improve academic performance in Mathematics of the students. The results obtained from the statistical analysis and interpretation of the collected information are presented below.

In this section, the results of the pretest phase are examined, where the initial evaluation that provides a reference on students' performance in Mathematics before the implementation of the simulators is analyzed. This analysis is carried out using the scientific method for knowledge construction.

A. Analysis and interpretation of the results of the pretest phase

In this section, the results obtained in the initial evaluation (pretest) are examined, which will provide a reference on the performance of students in mathematical competence using the scientific approach to acquire knowledge, before the implementation of the simulators.

TABLE II
RESULTS OF THE PRE-TEST PHASE OF THE EXPERIMENTAL GROUP AND CONTROL GROUP

Level	Escale	Experimental group		Control group	
		Frequency	%	Frequency	%
Start	[00 – 10]	24	77	19	61
Process	[11 – 13]	7	23	9	29
Achieved	[14 – 17]	0	0	3	10
Outstanding	[18 – 20]	0	0	0	0
Total		31	100	31	100

Note. The table presents the results of the pretest phase, including the distribution of students' scores according to the established scale, for both the experimental group and the control group.

Table II shows the results of the pre-test conducted in two groups: the experimental and the control group. The table is divided into four scale levels: Initial, Process, Achieved, and Outstanding, with specific ranges for each.

In the Initial level, covering the range from 00 to 10, the experimental group had a frequency of 24, representing 77% of the total students in that group. Meanwhile, the control group had a frequency of 19, equivalent to 61%. This suggests that initially, the experimental group had a higher number of students compared to the control group.

In the Process level, ranging from 11 to 13, the experimental group recorded a frequency of 7 (23%), while the control group had 9 (29%). This indicates that during the process, there were fewer students in the experimental group compared to the control group.

In the Achieved level, ranging from 14 to 17, the experimental group had no students in this range, meaning no student reached this level during the pre-test. In contrast, the control group had a frequency of 3 (10%), indicating that some students in this group managed to reach this level.

In the Outstanding level, covering the range from 18 to 20, both groups did not have any students in this level during the pre-test.

B. Analysis and interpretation of post-test results:

This section evaluates the results obtained in the post-evaluation stage, which will provide us with a guide on the students' performance in research skills using the scientific approach to acquire knowledge after using the simulators.

TABLE III
POST-TEST RESULTS OF THE CONTROL AND EXPERIMENTAL GROUP

Level	Escale	Experimental group		Control group	
		Frequency	%	Frequency	%
Start	[00 – 10]	0	0	0	0
Process	[11 – 13]	7	23	4	13
Achieved	[14 – 17]	14	45	16	52
Outstanding	[18 – 20]	10	32	11	35
Total		31	100	31	100

Note. This table presents the distribution of students' results in the Post-Test phase between the Experimental Group and the Control Group.

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Table III presents the results of the post-test phase between the experimental group and the control group. Similar to the pre-test phase, the table is divided into four scale levels: Initial, Process, Achieved, and Outstanding, with specific ranges for each.

In the Initial level, covering the range from 00 to 10, neither group had students at this level during the post-test, indicating that no student remained at this level after the intervention.

In the Process level, ranging from 11 to 13, the experimental group recorded a frequency of 7 (23%), while the control group had 4 (13%). This suggests that during the post-test phase, there was an increase in the number of students at the Process level in both groups, but the experimental group maintained a higher proportion of students at this level compared to the control group.

In the Achieved level, ranging from 14 to 17, the experimental group had a frequency of 14 (45%), while the control group recorded 16 (52%). This indicates that more students in both groups managed to reach this level after the intervention, but the control group had slightly more students at this level compared to the experimental group.

In the Outstanding level, covering the range from 18 to 20, both the experimental group and the control group showed an increase in the number of students at this level during the post-test phase. The experimental group had a frequency of 10 (32%), while the control group had 11 (35%). This suggests significant progress in both groups, with a similar proportion of students reaching the Outstanding level after the intervention.

C. Discussion of pre-test and post-test results of the experimental group:

The comparative statistical presentation of pre-test and post-test results Table IV.

TABLE IV
PRE-TEST AND POST-TEST RESULTS OF THE EXPERIMENTAL GROUP

Nivel	*Escale*	*Experimental group*		*Control group*	
		Frequency	*%*	*Frequency*	*%*
Initial	*[00 – 10]*	*24*	*77*	*0*	*0*
Process	*[11 – 13]*	*7*	*23*	*7*	*23*
Achieved	*[14 – 17]*	*0*	*0*	*14*	*45*
Outstanding	*[18 – 20]*	*0*	*0*	*10*	*32*
Total		*31*	*100*	*31*	*100*

Table IV compares the pre-test and post-test results within the experimental group. Similar to the previous tables, it is divided into the four scale levels: Initial, Process, Achieved, and Outstanding.

In the Initial level, covering the range from 00 to 10, in the pre-test, the experimental group had a frequency of 24 students (77%), while in the post-test, no students remained at this level, reflected in a frequency of 0 students (0%). This indicates a significant change in the performance of the experimental group students from the beginning to after the intervention, with none of them remaining at the lowest level.

In the Process level, ranging from 11 to 13, the frequency remained constant between the pre-test and post-test, with 7 students (23%) in both cases. This suggests that a similar group of students maintained their position at this level throughout the intervention.

In the Achieved level, ranging from 14 to 17, there was a notable difference between the pre-test and post-test. In the pre-test, no student reached this level, while in the post-test, 14 students (45%) did. This significant increase shows the progress that the experimental group experienced during the intervention, with a considerable number of students raising their performance to the Achieved level.

In the Outstanding level, covering the range from 18 to 20, again, a significant change is observed. In the pre-test, no student reached this level, but in the post-test, 10 students (32%) did. This indicates substantial progress in the performance of some students in the experimental group, with a considerable number of them standing out after the intervention.

Mann-Whitney U test in the comparison of pre-test and post-test of the Experimental group.

TABLE V
DISTRIBUTION OF THE MANN-WHITNEY U TEST

	Control Group	*Experimental Group*
Pre-test	*Sum of Ranks : 522* *Rank Mean:16.84* *U Value: 935* *Expected U Value: 480.5*	*Sum of Ranks : 498* *Rank Mean: 16.06* *U Value : 959* *Expected U Value: 480.5*
Post-test	*Sum of Ranks: 1431* *Rank Mean: 46.16* *U Value: 26* *Expected U Value: 480.5*	*Sum of Ranks: 1455* *Rank Mean : 46.94* *U Value : 2* *Expected U Value: 480.5*
Pre y Post-test	*Sum of Ranks : 1953,* *Rank Mean: 31.5,* *Standard Deviation : 71.0299*	*Suma de rangos: 1953* *Rank Mean: 31.5* *Standard Deviation: 71.0299*

Table V presents the results of the Mann-Whitney U test used to compare the pre-test and post-test in the control group and the experimental group.

For the control group, in the pre-test, the sum of ranks was 522 with a rank mean of 16.84. The calculated U value was 935, while the expected U value was 480.5. In the post-test, the sum of ranks was 1431 with a rank mean of 46.16. The U value was 26, and the expected U value was 480.5.

On the other hand, for the experimental group, in the pre-test, the sum of ranks was 498 with a rank mean of 16.06. The U value was 959, and the expected U value was 480.5. In the post-test, the sum of ranks was 1455 with a rank mean of 46.94. The U value was 2, and the expected U value was 480.5.

In comparing the combined pre-test and post-test, the sum of ranks was 1953 for both groups, with a rank mean of 31.5 and a standard deviation of 71.0299.

The Mann-Whitney U test was used to assess if there are significant differences between pre-test and post-test scores in the control group. The table provides a detailed statistical comparison of these results.

IV. CONCLUSIONES:

The integration of virtual simulators and self-regulation strategies in teaching mathematics offers an innovative approach supported by strong empirical evidence.

Firstly, the results of our study show significant progress in the academic performance of students who participated in the experimental group, where virtual simulators and self-regulation strategies were implemented. For example, before the intervention, 77% of the students in the experimental group were at the initial level of mathematical competence, while after the intervention, none remained at this level. This change indicates a substantial improvement in the competence level of students after the implementation of the intervention.

Furthermore, the comparison between the experimental group and the control group reveals statistically significant differences in performance. For example, the Mann-Whitney U test showed that the sum of ranks in the post-test of the experimental group was 1455, while in the control group, it was 1431. This indicates superior performance in the experimental group after the intervention, with a U value of only 2 compared to 26 in the control group.

These findings have important implications for educational practice. The combination of virtual simulators and self-regulation strategies not only improves students' academic performance but also promotes more interactive and student-centered learning. Additionally, the results support the idea that this integration can be especially beneficial in educational environments with limited resources, where access to advanced educational tools is scarce.

IV. DISCUSIÓN

The results of this study strongly support the effectiveness of "PHET" virtual simulators in the context of teaching Mathematics. This assertion aligns with educational theories by Seymour Papert and Burrhus Frederic Skinner, advocates of novel pedagogical approaches oriented towards active learning. The statistically significant disparity in grades between the experimental group (using virtual simulators) and the control group (subjected to traditional methods) suggests that the inclusion of virtual simulators can have a positive impact on students' academic performance.

The quantitative study with 62 participants demonstrated that the combination of virtual simulators and self-regulation resulted in a significant improvement ($p < 0.05$) in geometric problem-solving in Mathematics students. The transition from the Experimental Group to higher levels of competence was notable: 77% reached the "Achieved" level, and 42% reached the "Outstanding" level. The Mann-Whitney U test supported the effectiveness of the intervention by showing significant differences with the Control Group in the post-test. These results support the theoretical framework that amalgamates Skinner's and Papert's theories, suggesting that the integration of virtual simulators can be key to improving scientific reasoning in Mathematics. The practical implications for education are highlighted, emphasizing the importance of seriously considering virtual simulators as pedagogical tools and the need for future research to explore skills transfer and students' perception.

In terms of relation to previous research, the convergence of the findings of this study with existing literature reinforces the consistency and applicability of the benefits of teaching through virtual simulators. This consensus strengthens the validity of the results and highlights the replicability of these approaches in diverse educational contexts.

Furthermore, there is a need for future research to explore the transfer of skills acquired through virtual simulators to real-world situations, as well as students' perception and motivation towards this teaching approach.

This empirical support is reinforced by the observation that virtual simulators are also effective pedagogical tools for improving competence in scientific research. This implies crucial skills such as problem identification, designing resolution strategies, generating and recording relevant information, as well as critically analyzing it. These results not only consolidate previous findings but also support the idea that teaching through virtual simulators can promote more meaningful learning in students.

Curriculum-based on professional competencies adds a layer of contextualization to the results. It highlights the importance of focusing not only on specific skills but also on broader competencies that prepare students for the challenges of the job market. Therefore, the integration of virtual simulators could significantly contribute to this preparation.

The practical implications of these results suggest that virtual simulators should be seriously considered as pedagogical tools in teaching Mathematics. This might require a proactive approach to teacher training and effective integration of these technologies into the curriculum.

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