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USO DE SIMULAÇÕES COMPUTACIONAIS COMO ESTRATÉGIA DIDÁTICA DE ENSINO E DE APRENDIZAGEM DO TÓPICO "EFEITO FOTOELÉTRICO": ESTUDO DE CASO

USE OF COMPUTER SIMULATIONS AS A DIDACTIC TEACHING AND LEARNING STRATEGY OF THE TOPIC "PHOTOELECTRIC EFFECT": CASE STUDY

USO DE SIMULACIONES POR COMPUTADORA COMO ESTRATEGIA DIDÁCTICA DE ENSEÑANZA Y APRENDIZAJE DEL TEMA "EFECTO FOTOELÉTRICO": ESTUDIO DE CASO

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RESUMO

Introdução: A pesquisa encontra o seu fundamento em factos científicos de artigos que discutem estratégias didáticas utilizadas no ensino e na aprendizagem do efeito fotoelétrico, tendo como base o uso das simulações computacionais.
Objetivo: Desenvolver uma estratégia eficaz de utilização de simulações computacionais no ensino do tópico "efeito fotoelétrico" de modo a melhorar as aprendizagens dos alunos.
Métodos: O estudo foi realizado numa Escola Secundária Pública localizada no distrito de Inharrime, a sul de Moçambique.
Para a recolha de dados foi realizada uma pesquisa qualitativa e quantitativa, contando com a participação de uma amostra de quarenta (40) alunos do 12º ano do ensino médio, divididos em quatro turmas de dez alunos cada, sendo uma turma de controlo e as outras três de grupo experimental (onde foi aplicada a estratégia metodológica aqui proposta, baseada na realização das atividades laboratoriais seguidas da utilização de uma simulação computacional). Nas quatro turmas foi aplicado um pré-teste com o objetivo de avaliar o nível inicial de conhecimentos dos alunos, e um pós-teste para avaliar não só o contributo das atividades laboratoriais assim como da simulação computacional nas aprendizagens do tópico "efeito fotoelétrico".
Resultados: Os resultados deste estudo mostram que o uso de simulações computacionais associadas ou não com uma experiência laboratorial, contribui para uma aprendizagem mais eficaz sobre o tópico "efeito fotoelétrico".
Conclusão: De acordo com os resultados desta pesquisa, sugere-se a realização de uma experiência laboratorial aliada ao uso de simulações computacionais como uma alternativa para a prática pedagógica, uma vez que facilita a compreensão dos conteúdos por parte dos alunos, resultando em aprendizagens mais significativas.

Palavras-chave: simulação computacional; efeito fotoelétrico; mediação do professor; capacidade de perceção

ABSTRACT

Introduction: The research is based on scientific facts from articles that discuss didactic strategies used in the teaching and learning of the photoelectric effect based on the use of computer simulations.
Objective: To develop an effective strategy for using computer simulations to teach the topic of the "Photoelectric Effect" to improve student learning.
Methods: The study was carried out in a Public Secondary School located in Inharrime District, southern Mozambique.
For data collection, both qualitative and quantitative research was conducted, involving a sample of forty (40) 12th-grade students divided into four groups of ten students each. One group was a control group, while the other three were experimental groups, where the proposed methodological strategy was applied based on performing laboratory activities followed by a computer simulation. A pre-test was administered to all four groups to assess the student's initial level of knowledge, and a post-test was given to evaluate the contribution of the laboratory activities and the computer simulation to the student's learning of the topic "photoelectric effect."
Results: The results of this study show that the use of computer simulations, whether combined with a laboratory experiment or not, contributes to more effective learning of the topic "photoelectric effect."
Conclusion: According to the results of this research, a combination of laboratory experiments with computer simulations is recommended as an alternative pedagogical practice since this approach facilitates students' understanding of the content, leading to more meaningful learning.

Keywords: computer simulation; photoelectric effect; teacher mediation; perception ability

RESUMEN

Introducción: La investigación encuentra su fundamento en hechos científicos a partir de artículos que discuten estrategias didácticas utilizadas en la enseñanza y aprendizaje del efecto fotoeléctrico, basadas en el uso de simulaciones por computadora.
Objetivo: Desarrollar una estrategia efectiva para el uso de simulaciones por computadora en la enseñanza del tema "efecto fotoeléctrico" con el fin de mejorar el aprendizaje de los estudiantes.
Métodos: El estudio se llevó a cabo en la Escuela Secundária Pública ubicada en el Distrito de Inharrime, al sur de Mozambique.
Para la recolección de datos se realizó una investigación cualitativa y cuantitativa, con la participación de una muestra de cuarenta (40) estudiantes del año 12 de secundaria, divididos en cuatro clases de diez estudiantes cada una, siendo una clase de control y las demás de un grupo experimental (donde se aplicó la estrategia metodológica aquí propuesta, basada en la realización de actividades de laboratorio seguidas del uso de una simulación por computadora). En las cuatro clases se aplicó un pretest con el objetivo de evaluar el nivel inicial de conocimientos de los estudiantes, y un postest para evaluar no solo el aporte de las actividades de laboratorio así como la simulación por computadora en el aprendizaje del tema" efecto fotoeléctrico".
Resultados: Los resultados de este estudio muestran que el uso de simulaciones por computadora, asociadas o no a un experimento de laboratorio, contribuye a un aprendizaje más efectivo sobre el tema "efecto fotoeléctrico".
Conclusión: De acuerdo a los resultados de esta investigación, se sugiere realizar un experimento de laboratorio combinado con el uso de simulaciones por computadora como una alternativa a la práctica pedagógica, ya que facilita la comprensión de los contenidos por parte de los estudiantes, resultando en aprendizajes más significativos.

Palabras Clave: simulación por computadora; efecto fotoeléctrico; mediación docente; capacidade de percepción

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INTRODUCTION

Considering that the integration of computer simulations in teaching should not occur mechanically and must adhere to teaching characteristics that enhance the learning context, a study was conducted to investigate strategies for using computer simulations in the teaching of the topic "photoelectric effect.” According to Costa, quoted by Gilberto and Coutinho (2010:112), “The use of technologies in schools has a long history; however, like in other scientific fields, it only became a new area of study and research in the last century."

Currently, several studies are available in the literature on using computer simulations in teaching Physics. For example, we highlight the research conducted by Athanassios and Vassilis (2001) on the role of computer simulations in developing a functional understanding of the concepts of velocity and acceleration in projectile motion. They concluded that computer simulations can be an alternative teaching tool to help students overcome cognitive constraints and develop a functional understanding of Physics.

Sarabando et al. (2014) researched the contribution of computer simulations to students' learning of Physics concepts (weight and mass). The results show that the overall gains were greater when students used computer simulations, either on their own or in conjunction with laboratory activities. However, they found that the total gains achieved depended on the teacher's mediation during the computer simulation.

Eliphas and Shumba (2019) studied the impact of integrating computer simulations and videos, along with lecture discussions, on students' understanding of atomic physics and radioactivity concepts. The results demonstrated that these technologies effectively support the learning of certain concepts related to atomic physics and radioactivity. This can be explained by the fact that, in computer simulations, students can take control, input data values, and observe the simulation and results almost immediately. This adds a practical dimension and brings the activity closer to reality, making learning environments more motivating.

Kabigting (2021) conducted a study to assess the effects of computer simulations and conventional Physics teaching on the learning of concepts among high school students. The study concluded that there was no significant difference between the pre-test results of the experimental and control groups. However, the difference between the post-test results of the two groups was very significant, as was the difference between the pre-test and post-test results within both groups.

Sá et al. (2022) explored an approach suitable for high school education on an advanced Physics topic, spontaneous symmetry breaking, using the analogy between simple harmonic and anharmonic oscillators, a fundamental subject for the Higgs Mechanism. The authors proposed using a computer simulation, employing the software *Modellus*, to study the energy of the oscillators. Visualizing the symmetry-breaking problem through computer simulations enables students to conduct their investigations easily.

In this context, the inclusion of the area of practical and technological activities, which encompasses Information and Communication Technologies (ICT), in the Secondary Education Curriculum (PCESG) in Mozambique is a significant innovation. According to the National Institute for Educational Development (2007), the central aim of this area is to "develop skills oriented towards practical activities related to psychomotor, aesthetic, and life-useful abilities, to promote an integral development of the individual."

Problem Statement

The topic being discussed arises from the problem of students' perception of the “photoelectric effect” and aims to link this knowledge with observable phenomena in their daily lives. Among the root causes of failure in learning this topic are teaching strategies that do not keep pace with the evolution of learning theories, the lack of conventional Physics laboratories in most Mozambican schools, particularly in the institution under consideration, which makes it practically unfeasible to conduct experimental practical lessons to verify physical concepts, especially regarding the “photoelectric effect.”

In this study, the use of computer simulators is suggested, as it is a tool that can represent reality with great similarity, allowing students to gain a realistic perspective through computer simulations. This helps students develop skills and convictions aimed not only to improve their learning outcomes but also to enhance their analytical skills and motivation.

This study aims to explore and develop an effective strategy for using computer simulations to teach the "photoelectric effect" to enhance students' learning.

The Research Question guiding this investigation is formulated as follows: "How can practical activities on the 'photoelectric effect' be conducted using computer simulations to promote better student learning?"

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1. THEORETICAL FRAMEWORK

Physics is generally taught in a "traditional" manner, where the teacher acts as the main presenter and generator of questions, being the central figure in the teaching and learning process. Even when using learning resources, such as audiovisual aids and experiments, the teacher remains the active element in the classroom, delivering lectures, conducting experiments, and solving the problems they propose, with the student being regarded as a passive participant.

Lopez and Pinto (2017) analyzed how high school students interpret the visual representations displayed in PhET simulations. The authors opted for a case study involving two working groups (experimental and control), where an experiment was conducted with the experimental group. The results indicate that visual representations in computer simulations do not necessarily lead to a complete understanding of the scientific content by the student. This process requires reading skills, prior knowledge, attention, and external support. Teachers need to consider these factors to help their students interpret the images in computer simulations and fully harness their educational potential.

Sousa and Pereira (2017) wanted to identify the contributions of a didactic sequence involving the use of computer simulations for the teaching and learning of the topic "photoelectric effect" based on three pedagogical stages. The proposed didactic strategy consists of an initial problematization, a theoretical discussion, and a computer simulation.

In the article by Supurwoko et al. (2017), an attempt is made to demonstrate that in a lesson with computer simulations, students can develop a better conceptual understanding of the topic "photoelectric effect" than in a traditional lesson without simulations.

In a study carried out by Kunnath and Kriek (2018) to determine a more effective pedagogy in improving the understanding of 12th-grade students in learning the topic "photoelectric effect" with the use of computer simulations as a demonstration tool and promoter of semi-autonomous learning, it was concluded that in a class where computer simulations are used to enable learning, the teacher's role in handling the simulations is essential, as they must guide the students in their learning to ensure the understanding of the content under study.

On the other hand, Muniz et al. (2018) made a methodological proposal on the photoelectric effect for secondary education to explain how low-cost experiments enable students to have a more realistic learning experience and how computer simulations can promote learning. The study involved a conventional low-cost experimental practice followed by a computer simulation.

Based on the results of Siswoyo's (2019) study on the development of a teacher's guide with methodological instructions for teaching and learning the topic 'photoelectric effect' using a strategy he called POE (Predict-Observe-Explain) aided by the use of the PhET simulator, it shows the need for students to follow a teacher's guide to facilitate teacher mediation as well as student learning.

Ariyani et al. (2020) carried out a study involving four primary school students to analyze the effectiveness of using the PhET simulator to understand the topic of the "photoelectric effect" using a script so that the students could learn independently. Observation sheets, questionnaires, and interviews were used to collect the data, and the results show that the strategy of using PhET simulations aided by a script can be considered effective in helping students explore the topic of the "photoelectric effect" independently.

The articles analyzed make use of PhET computer simulations, with some following Ausubel's (1963) theory of meaningful learning, according to which the student confronts the new knowledge with the one that already exists in their cognitive structure, and others, such as Piaget (1954) and Bruner (1960), following constructivism, in which the student builds new concepts based on previous knowledge and on the knowledge being studied. As for the articles analyzed, all of them have the main objective of promoting meaningful learning and using computer simulations as a tool to motivate student participation, promote autonomous learning, visualize results, or enable greater student interaction in the teaching-learning process.

2. DESCRIPTION OF THE STUDY

To investigate the effectiveness of the PhET computer-based educational resource in the learning of the topic "photoelectric effect," a quasi-experimental methodological approach was adopted, involving a sample of 40 12th-grade students from a public secondary school located in the Inharrime District, southern Mozambique. Two interventions were conducted, as described in section 2.1.

Before implementing the proposed activities, a pre-test was administered to all groups to assess the student's initial level of knowledge, and a post-test was conducted to evaluate the learning outcomes after teaching the "photoelectric effect" topic using each methodological strategy.

Each class lasted 90 minutes, while the pre-test and post-test each lasted 45 minutes.

2.1. Learning through computer simulation

In the first phase, a preliminary study was carried out to assess the impact of the PhET computer simulation as a didactic resource for learning the topic "photoelectric effect" with 20 students. These students were divided into two groups of equal numbers, making up Classes A (Control Group) and B (Experimental Group).

Before carrying out the proposed activities, the same pre-test was administered to both classes in order to assess the student's initial level of knowledge on the topic of the "photoelectric effect."

Table 1 shows the activity implementation plan for the lesson on the "photoelectric effect" in the Modern Physics thematic unit.

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Table 1 – Activity Implementation Plan

Class A	Class B
Lecture-based Class	Computer Simulation Activities followed by a Theoretical Lecture

The activities in Class A predominantly consisted of lectures on the topic of the "photoelectric effect," while in Class B, the lecture was preceded by a computer simulation.

Figure 1 compares the teaching performance (percentage of students with grades equal to or greater than 10, on a scale of 0 to 20) obtained from the pre-test and post-test results in Classes A and B.

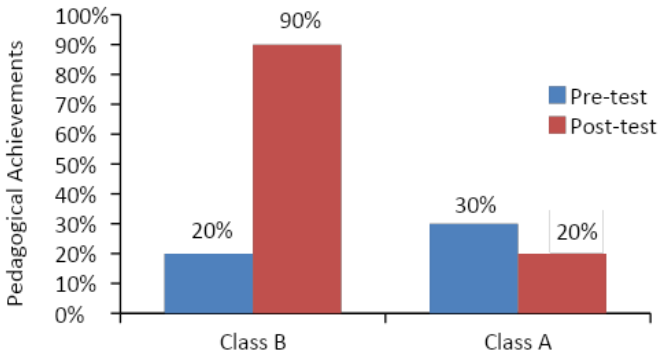

Figure 1 – Comparison of pre-test and post-test teaching performance in Class A and Class B

Figure 1 shows that:

- The initial level of student knowledge regarding the basic concepts of the "photoelectric effect" topic is low for both groups, with 20% for group B and 30% for group A.
- The group that used the computer simulation on the "photoelectric effect" achieved better learning outcomes, as reflected in the post-test results.
- The PhET computer simulation appears to be an effective educational resource that contributes to improving the teaching and learning process, as 90% of the students in Group B achieved positive post-test evaluations, compared to only 20% of the students in Group A. This suggests that conducting practical lessons using the PhET simulation can be an important factor in acquiring knowledge about the "photoelectric effect" topic.
- The 10% decrease in the pedagogical performance of group A suggests, for this study, an uncertainty in the assessment of pedagogical performance of at least 10%.

2.1.1. Learning Achievements in Classes A and B

Observing Tables 2 and 3 presented below, it is possible to note that the Gross Gain, the difference between the post-test and pre-test grades, is positive for all students except for one student in group A. On average, the students in group B achieved a Gross Gain of 5.6, in contrast to the Gross Gain of 2.2 for group A.

Table 2 – Individual and collective Gains of Class A students

Student	Pre-Test Grade	Post-Test Grade	Gross Gain	Relative Gain (%)
A1	3	7	4	23.5
A2	0	2	2	10
A3	11	13	2	22.2
A4	5	8	3	20
A5	5	6	1	6.7
A6	2	7	5	27.8
A7	10	8	-2	-20
A8	4	6	2	12.5
A9	10	11	1	10
A10	1	5	4	21.1
Class A	Average pre-test grades 5.1	Average post-test grades 7.3	**Average Gross Gain** 2.2	**Relative Collective Gain (%)** **14.8**

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Table 3 – Individual and collective gains of Class B students

Student	Pre-Test Grade	Post-Test Grade	Gross Gain	Relative Gain (%)
B1	0	10	10	50
B2	10	13	3	30
B3	0	5	5	25
B4	8	11	3	25
B5	10	14	4	40
B6	6	10	4	28.6
B7	7	12	5	38.5
B8	1	10	9	47.4
B9	6	12	6	42.9
B10	3	10	7	41.2
Class B	Average pre-test grades	Average post-test grades	**Average Gross Gain**	**Relative Collective Gain (%)**
	5.1	10.7	5.6	**37.5**

Still considering Tables 2 and 3 above, it is possible to see that the Individual Relative Gain for class A is less than 28%, while for the students in class B, whose lessons were taught using computer simulations, the gains are between 25% and 50%.
The Collective Gain of Class B (37.5 percent) was higher than the Gain of Class A (14.8 percent).
The Relative Gain is determined by the equation:

$$RG\ (\%) = \left(\frac{Y-X}{T-X}\right) \times 100 \qquad (1)$$

RG – Relative Gain
Y – Post-Test Grade
X – Pre-Test Grade
T - Maximum grade (20 points) obtained in the tests.
For the statistical analysis of the data, an independent T-test was also conducted, comparing the pre-test and post-test results for each of the two groups. The aim was to statistically infer whether there was any significant gain in student learning. In this regard, two regions were defined: a non-rejection region for the null hypothesis (NRR) set at 0.95 (95%) and a rejection region for the null hypothesis, also known as the critical region (CR), set at 0.05 (5%).
Thus, it was examined whether there is a significant difference between the average Relative Gain of group A and group B, considering the following hypotheses:
Hypothesis H0: The average Relative Gains in groups A and B are equal.
Hypothesis H1: The average Relative Gains in groups A and B are different.
Tables 4 and 5 below present the description of the Student's T-test results between the average Relative Gains in groups A and B, using the statistical software SPSS.

Table 4 – Results of the Student's T-test of the Independent Relative Gain

Relative Gain	Group Statistics			
	Grade	Average	Standard Deviation	Standard Error of the Mean
Class A	10	14.20	0.77	0.24
Class B	10	35.53	0.83	0.26

Table 5 – Independent samples test

Relative Gain	Levene's test for equality of variables		T-test for equality of means						
	F	Sig.	t	Df	Sig. (2-extremities)	Difference in means	Standard Error Difference	95% confidence interval of the difference Minimum	Maximum
Equal variances assumed	0.241	0.627	7.940	28.000	0.000	2.333	0.294	1.731	2.935
Equal variances are not assumed.			7.940	27.849	0.000	2.333	0.294	1.731	2.935

Tables 4 and 5 above indicate that the difference in means between classes A and B is statistically significant, thus justifying the trend of the significance level at 0%, below the 0.05 parameter (5%). However, the null hypothesis (H0) falls within the rejection zone, so it was rejected.
Figure 2 shows the comparison between the Relative Gain in Class A and Class B.

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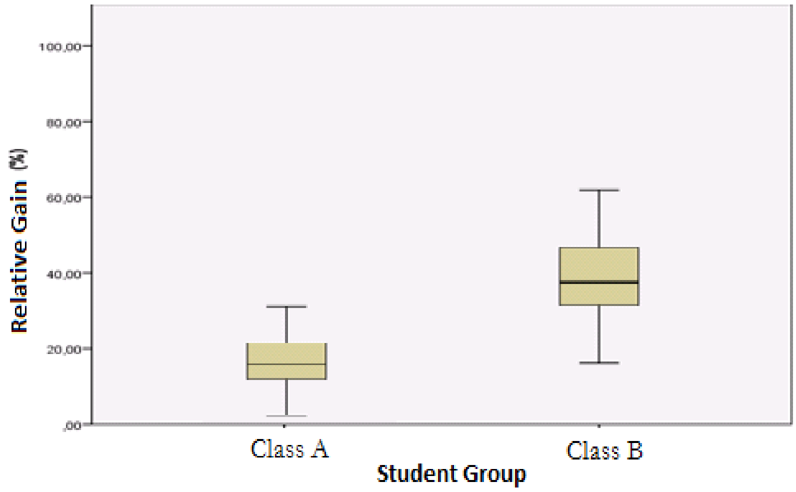

Figure 2 – Comparison between Relative Gain in Class A and Class B

Figure 2 shows that the difference in the Relative Gain averages between Class A and Class B is significant, which leads us to conclude that the use of computer simulation as a didactic strategy in the teaching and learning of the topic "photoelectric effect" is an alternative that can facilitate the understanding of concepts.

2.2 Learning through laboratory experiments and computer simulations

In the second phase of the study, the sample (20 students) was divided equally into two classes of 10 students each. In one, the methodological strategy based on a laboratory experiment followed by a computer simulation was applied, and in the other, the order of the interventions was switched, i.e., the computer simulation was applied first, followed by the laboratory experiment. In both classes, a pre-test was administered to assess the student's initial level of knowledge, and a post-test was administered to assess their learning of the topic "photoelectric effect" for each of the methodological strategies.
The pre-test and post-test lasted 45 minutes each. The lesson in each of the classes lasted 90 minutes.
Table 6 shows the activity implementation plan that was followed for the lesson on the 'photoelectric effect' in the Modern Physics thematic unit.

Table 6 – Activity implementation plan

Class C	Class D
Practical activity to carry out a laboratory experiment followed by a computer simulation	Computer simulation followed by practical activity to carry out a laboratory experiment.

Figure 3 shows the outline of the activities in Class C, with three stages, the first of which consisted of carrying out a laboratory experiment on "photoelectric effect" in the classroom using low-cost alternative material, followed by a theoretical discussion on the topic under study, and finally a computer simulation was used to prove the theory studied.

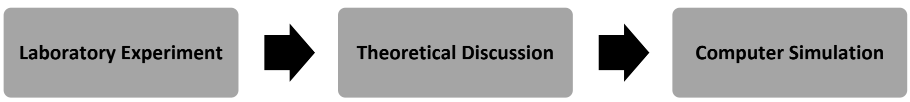

Figure 3 – Stages in the implementation of activities in Class C

Figure 4 shows the outline of the activities in Class D, which also had three stages, the first of which consisted of a computer simulation on the "photoelectric effect" topic, followed by a theoretical discussion on the topic under study, and finally, a laboratory experiment on the same topic in the classroom using a low-cost alternative material.

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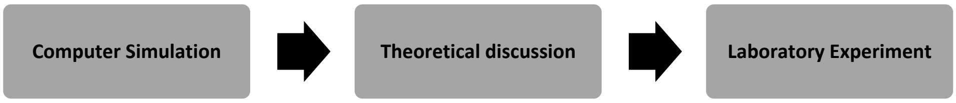

Figure 4 – Phases of implementation of activities in Class D

The use of computer simulations aims not only to motivate students to participate in learning but also to make it easier to visualize more complex phenomena.

While in the context of learning theories, the methodological model implemented in Class C aimed to use computer simulation to verify the theory studied, in the methodological model implemented in Class D, computer simulation served as the initial source of knowledge.

Figure 5 compares the pedagogical achievements (percentage of students with grades equal to or higher than 10, on a scale of 0 to 20) obtained from the pre-test and post-test results in Class C and Class D.

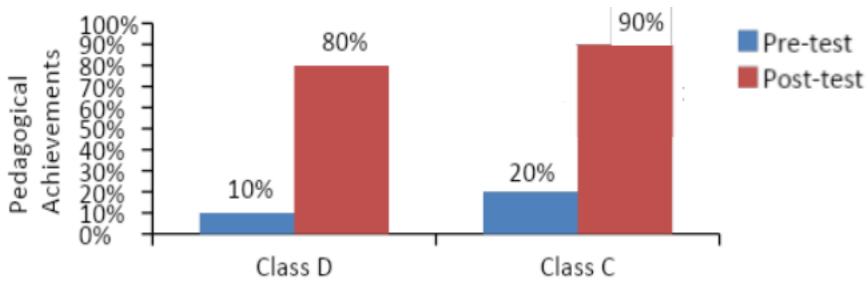

Figure 5 – Comparison of pre-test and post-test teaching achievements in Class C and Class D

Comparing the results of the pre-test and post-test, we can see that before the implementation of the two interventions (computer simulation and laboratory activity), the students in both classes had difficulties interpreting the concept of the "photoelectric effect," relating the energy of the photoelectrons emitted to the intensity of the incident radiation and the different types of metals available in the cathode. The results presented in Figure 5 show that there was a significant increase in the number of students with positive evaluations in the post-test in both classes (C and D), compared to the pre-test evaluations, which suggests that the implementation of computer simulations associated with laboratory activities is a didactic strategy that can make a significant contribution to student learning and that a computer simulation can be a very interactive tool capable of motivating students.

2.2.1. Learning gains in Classes C and D

Analyzing Tables 7 and 8 below, it can be seen that the Gross Gain is always positive, which indicates that, in general, there has been progress in the student's learning of the topic "photoelectric effect," both for Class C and Class D.

Table 7 – Individual and collective gains of Class C students

Student	Pre-Test Grade	Post-Test Grade	Gross Gain	Relative Gain (%)
C1	0	12	12	60
C2	4	16	12	75
C3	0	10	10	50
C4	12	16	4	50
C5	8	12	4	33.3
C6	0	16	16	80
C7	0	16	16	80
C8	12	16	4	50
C9	0	4	4	20
C10	4	12	8	50
Class C	Average pre-test Grades	Average Post-test Grades	**Average Gross Gains**	**Relative Collective Gain (%)**
	4	13	9	**56.25**

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Table 8 – Individual and collective gains of Class D students

Student	Pre-Test Grade	Post-Test Grade	Gross Gain	Relative Gain (%)
D1	12	16	4	50
D2	0	12	12	60
D3	4	16	12	75
D4	0	8	8	40
D5	0	12	12	60
D6	4	8	4	25
D7	8	20	12	100
D8	0	16	16	80
D9	4	16	12	75
D10	0	12	12	60
Class D	Average pre-test Grades	Average Post-test Grades	**Average Gross Gains**	**Relative Collective Gain (%)**
	3.2	13.6	10.4	**61.9**

Still considering Tables 7 and 8 mentioned above, it is noticeable that the Individual Relative Gain is always positive, with values equal to or above 50%, except for three students in Class C and two in Class D. This indicates that the students significantly improved their assessments on the "photoelectric effect" topic in the post-test compared to the pre-test. Thus, combining conventional laboratory experiments with computer simulations, the didactic strategy proposed here seems to promote more effective learning.

This study also highlights the fact that, although the collective gain for Class D (61.9%) is greater than for Class C (56.25%), the 5.65% difference may not be enough to emphasize the importance of the order in which the laboratory experiments and computer simulations were implemented.

Therefore, statistical analysis was conducted using an independent T-test to compare the pre-test and post-test results of Classes C and D to statistically infer whether there were significant learning gains. In this context, two regions were defined: a non-rejection region for the null hypothesis (NRR) set at 0.95 (95%) and a rejection region for the null hypothesis, also known as the critical region (CR), set at 0.05 (5%).

To determine whether there is a significant difference between the Collective Relative Gain of Class C and Class D, the following hypotheses were tested:

- **Hypothesis H0:** The average Relative Gains in Classes C and D are equal.
- **Hypothesis H1:** The average Relative Gains in Classes C and D are different.

Tables 9 and 10 below present the description of the Student's T-test results comparing the average Relative Gains in the control and experimental classes using the SPSS statistical software.

Table 9 – Results of the Student's T-test of the Independent Relative Gain

Relative Gain	Group statistics			
	N	Average	Standard deviation	Standard Error of the Mean
Class C	10	53.83	20.16	6.38
Class D	10	62.50	21.38	6.76

Table 10 – Independent samples test

Relative Gain	Levene's test for equality of variables		T-test for equality of means						
	F	Sig.	T	Df	Sig. (2-extremities)	Difference in means	Standard Error Difference	95% confidence interval of the difference: Minimum	Maximum
Equal variances assumed	0.000	0.991	-0.933	18	0.363	-8.670	9.291	-28.191	10.851
Equal variances are not assumed.			-0.993	17.938	0.363	-8.670	9.291	-28.195	10.855

Tables 9 and 10 show no statistically significant differences between the Relative Collective Gain in classes C and D, as p>0.05, where the significance level Sig=0.991, thus confirming Hypothesis H0. This means that statistically, there are no differences between the two methodological strategies for using computer simulations to teach the topic "photoelectric effect."

Figure 6 below shows a comparative analysis of the Relative Gain in Classes C and D.

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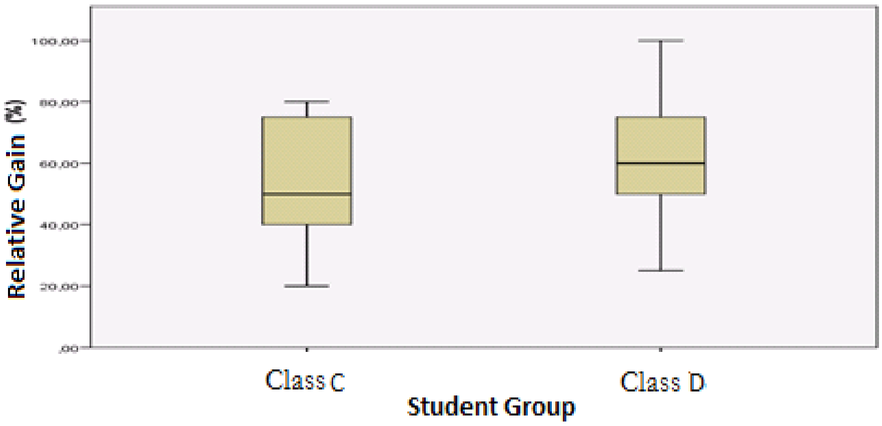

Figure 6 – Comparison of Relative Gain in Class C and Class D

Figure 6 shows that there are no significant differences in the Collective Relative Gains between Classes C and D, which leads us to suggest the following:

- Regarding how the teacher should mediate the teaching and learning of the topic "photoelectric effect" using computer simulations, a teaching strategy that values students' reflective interventions should be applied to promote effective learning.
- The use of computer simulations as a teaching strategy for the "photoelectric effect" topic can significantly contribute to student learning. This is because it is a tool that can motivate students to engage in the educational process, where they observe the behavior of the physical models proposed in the simulation, gain a better understanding of the concepts, and compare their prior knowledge with the scientific knowledge acquired through the execution, visualization, and analysis of the computer simulations.
- From the two interventions, it was possible to verify that while students learn through computer simulations in class when simulations were combined with laboratory experiments, their understanding of the physical concepts involved was more effective.

CONCLUSION

In general, the results of this study show successful learning outcomes when the lesson is mediated through computer simulations. Students feel motivated to participate in the production of knowledge, observe the behavior of the proposed physical models in the simulation, better understand the concepts by visualizing and analyzing the simulation data, and finally, confront their prior knowledge with the scientific knowledge acquired through the execution of the simulations.

From the analysis carried out in the second study, it is not possible to determine the most appropriate implementation design for making learning with computer simulations more effective. However, the implementation design used in Class D, which followed the sequence of computer simulation, followed by theoretical explanation, and then the laboratory activity, showed better collective learning gains.

On the other hand, using computer simulations can be considered an alternative to pedagogical practice, potentially facilitating students' understanding of concepts and leading to more meaningful learning outcomes.

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AUTHOR CONTRIBUTIONS

Conceptualization, R.E.M.; data curation, R.E.M., P.C. and A.S.; formal analysis, R.E.M., P.C. and A.S.; funding acquisition, R.E.M.; investigation, R.E.M.; methodology, R.E.M., P.C. and A.S.; project administration, R.E.M., P.C. and A.S.; resources, R.E.M., P.C. and A.S.; software, R.E.M., P.C. and A.S.; supervision, P.C. and A.S.; validation, P.C. and A.S.; writing-original draft, R.E.M.; writing-review and editing, P.C. and A.S.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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