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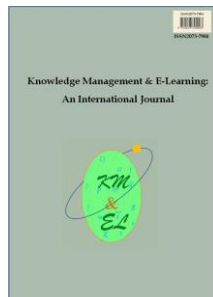
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Students' attitude towards physics: Its influence on their performance before and after the use of interactive simulations

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Abstract: Science education, particularly physics, remains a priority for many countries, as their future economic prosperity is closely linked to student success in science and technology. Given the persistent challenges faced by teachers in stimulating students' interest in this discipline, the integration of innovative teaching methods has become essential. This study aimed to examine changes in students' attitudes toward physics and explore the correlation between these attitudes and their performance before and after using interactive simulations based on the 5E learning model. This study was conducted with 127 Moroccan middle school students, who were divided into experimental and control groups. The teacher utilized interactive simulations to teach electricity and mechanics to the experimental group ($N = 62$) while adopting conventional teaching methods

for the control group ($N = 65$). To compare the students' attitudes and performance, the same attitude test was administered as a pre-test and a post-test before and after the study's implementation. Additionally, students' performance was obtained from the results of the first (pre-performance) and second (post-performance) semester physics exams. Data analysis was conducted using the Statistical Package for Social Sciences V24. The results show that using interactive simulations based on the 5E in physics teaching and learning has a positive impact on students' school performance and attitudes. Furthermore, the study showed no significant difference between boys and girls in their attitudes toward physics before and after the intervention. Additionally, the results indicated a significant positive correlation between students' attitudes toward physics and their performance in physics.

Keywords: 5E learning; Interactive simulation; Physical science; Student attitudes; Student performance

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1. Introduction

Students' attitudes toward science, particularly physics, are important factors in the teaching and learning processes, as they influence their school performance. Several studies have examined the factors that may contribute to poor student performance in physics, including the learning environment, parents' education level (Robert et al., 2024), teaching methods (Assem et al., 2023), lack of experienced teachers (Abamba, 2021), teacher characteristics (Korur & Eryilmaz, 2012), students' cognitive style, students' gender (Okoronka & Wada, 2014), extrinsic motivation, and prior experiences (Debacker & Nelson, 2000). However, most studies agree that students' attitudes toward physics play an important role in this poor performance. According to Hawkins and Phelps (2013), the concept of attitude has received vital attention from researchers over the past few decades in the field of science education. They have defined it as *"the positive or negative feelings acquired toward science, the beliefs students hold about physics, and the values one attributes to an object, as well as the impact of science on society"*. A negative attitude toward a subject hinders learning, whereas a positive attitude encourages students to invest effort, resulting in better outcomes in that subject (Veloo et al., 2015).

Many researchers have studied the relationship between students' attitudes and their performance scores in science subjects. Job and Paul (2023) found a significant relationship between students' attitudes and their performance scores in physics. Similarly, Narmadha and Chamundeswari (2013) demonstrated that students' attitudes toward science were correlated with their achievement in science at the secondary school level. In addition, students' attitudes are believed to enhance science learning outcomes (Saleh Alrawili et al., 2021). Gender differences in attitudes toward science have also been explored. Fatoba and Lawrence (2014) showed a slight difference in favor of girls in their attitudes toward physics, while Banu (1986) reported that boys in the United Kingdom had a more positive attitude toward science and preferred science-related careers compared to girls. However, Shaw (2004) found no significant gender difference in attitudes toward physics.

Akinbobola (2009) recommended cooperative learning strategies in schools to improve students' attitudes toward physics. Other researchers are trying to find a way to improve students' attitudes toward physics to improve their performance. In this regard, several studies have focused on using interactive simulations in physics learning (Faour & Ayoubi, 2018; Marušić & Sliško, 2012). Although these studies provide valuable insights, they do have certain limitations. Firstly, many of them focus on geographically specific or culturally homogeneous samples, which limits the generalizability of their results. In addition, some older studies, such as Banu's (1986), may not account for recent changes in educational contexts, particularly with the development of educational technologies. Furthermore, studies on gender differences reveal contradictory results, highlighting the need for further exploration using more robust methodologies and diverse samples.

1.1. Interactive simulations in physics science education

The 21st century has witnessed a surge in technology, leading to numerous advances and developments in physics science. Physics is considered a difficult subject because of its abstract concepts, which often result in negative attitudes toward the subject (Shi & Liang, 2012). To address this issue, interactive simulations have been created to assist students in enhancing their scientific knowledge and skills.

Many researchers in science education consider interactive simulations to be promising technological instruments for enhancing learning (Rutten et al., 2012). The use of interactive simulations, such as PhET, PCCL, Crocodile Physics, and Algodoo, offers numerous educational benefits. They reduce the time and effort required for experiments compared to traditional laboratories (Roschelle et al., 2000) and allow visualization of otherwise invisible phenomena, such as electrons and atoms (Wieman et al., 2010). They also provide learning experiences that would not be possible in a traditional laboratory (Perkins et al., 2014) and can substitute for experiments that are difficult to control or impossible to replicate in a laboratory setting (Ndihokubwayo, 2017).

The literature contains several studies examining the use of interactive simulations in physical science learning. Some researchers have used interactive simulations, such as PhET simulations, to investigate students' problem-solving skills in the context of inquiry-based learning (Yuliati et al., 2018), while others have explored using simulations to improve the effectiveness of traditional methods (Ben Ouahi et al., 2021; Hamamous & Benjelloun, 2023a). Other research investigates the effect of using simulations on students' attitudes toward physical science and the relationship with their performance. Aÿıksoy and Islek (2017) concluded that virtual laboratory experiments had a favorable impact on students' attitudes. Similarly, the study conducted by Ayasrah et al. (2024) evaluated the impact of using computer simulations on students' attitudes toward physics. Ninety students were divided into an experimental group, which used simulations, and a control group, which followed traditional teaching methods. The findings revealed that students in the experimental group had relatively higher positive attitudes toward physics compared to those in the control group. Furthermore, Penn and Ramnarain (2019) suggest that virtual simulations are a supplementary learning tool that can enhance students' attitudes toward chemistry. Additionally, students perceive these simulations as helpful for visualizing abstract chemical concepts. Meanwhile, the study conducted by Kattayat et al. (2016) revealed a notable positive relationship between students' performance in physics and their attitude towards physics when exposed to simulation-based learning.

In this study, we used interactive simulations tailored to fit the 5E learning model. The 5E pedagogical model, developed by Roger Bybee, is a form of inquiry-based learning based on research findings outlined in the National Science Education Standards (Harris, 1997). It replaces memorization-based learning and consists of five steps: engage, explore, explain, elaborate, and evaluate. Today, it is commonly implemented using virtual laboratories and is an effective pedagogical tool for improving student achievement (Akhigbe & Adeyemi, 2020). Furthermore, it produces considerable concept change in students with different backgrounds (Sarı et al., 2017). Another study found that the 5E model improved students' knowledge, enhanced their motivation to learn, and improved their understanding of abstract concepts in electricity (Guzel, 2017). In addition, Sarı et al. (2017) noted that this model promotes the creation of an environment that improves students' attitudes toward the physical sciences and corrects students' misconceptions. It helps students to explain phenomena based on evidence and also allows them to gain autonomy from the teacher (Makamu & Ramnarain, 2022).

1.2. Study problem

Physical science is often considered the most challenging of the fundamental sciences for students (Jarmouni, 2021), and struggling with it can lead to negative attitudes toward physics, which, in turn, can be linked to poor performance (Shi & Liang, 2012). In Morocco,

various studies have indicated that middle school students perform relatively poorly in the sciences, particularly in physical sciences (Conseil Supérieur de l'Éducation, de la Formation et de la Recherche Scientifique & Instance Nationale d'Évaluation, 2016; Nasser et al., 2017). Additionally, the findings of TIMSS 2019 (Mullis et al., 2019), which measure the science and mathematics skills of elementary and middle school students, show that Morocco ranks at the bottom among countries in terms of students' aptitude for mathematics and science. Moreover, the results of the PISA 2022 (Programme for International Student Assessment) (OCDE, 2023) study show that only 25% of Moroccan students attain the level of basic competence in science, which falls far below the OCDE average (76%). As a result, exceptional performance in science is thus virtually absent. However, Morocco is slightly ahead of the TIMSS 2015 (Provasnik et al., 2016) and at the bottom of the OCDE survey (Schleicher, 2019) in terms of overall performance in reading, science, and mathematics. Many studies examining student performance in physics have found that negative student attitudes toward science are a primary factor contributing to poor performance. In Morocco, only 35% of second-year middle school students have a positive attitude toward science (Mullis et al., 2019). In addition, Provasnik et al. (2016) found that Moroccan students with very positive attitudes obtained better results than those with negative attitudes.

The literature indicates that most research on interactive simulations, particularly virtual labs, has focused on university and high school students, with relatively few studies addressing their effects on middle school students. Studies carried out with middle school students are rare. Several studies have been carried out in the Moroccan literature using interactive simulations. These studies examine their effectiveness in teaching the physical sciences (Hamamous & Benjelloun, 2023b; Mrani et al., 2020; Ben Ouahi et al., 2022), students' and teachers' opinions on their use (Ben Ouahi et al., 2020), and students' attitudes toward their use (Ben Ouahi et al., 2023). Additionally, the study conducted by Ben Ouahi et al. (2022) identified and analyzed science teachers' perspectives on the effectiveness of PhET interactive simulations in teaching and enhancing student learning. This early research is insufficient in examining the long-term effects of interactive simulations on student learning outcomes and how effectively simulations are used in the classroom. This study stands out by using simulations based on the 5E learning model to explore third-year middle school students' attitudes toward physics and their school performance before and after using interactive simulations. In contrast to previous studies, this research focuses specifically on this age group and employs an innovative methodology to examine aspects that have been little explored to date, such as long-term effects and classroom effectiveness, thus offering a unique and relevant contribution to the existing literature. The importance of this study lies in integrating interactive simulations based on the 5E model into the teaching of physical sciences to foster the attitudes of third-year middle school students towards physical sciences and encourage them to pursue studies in science and technology in high school. Indeed, at the end of this year, students and their families decide whether to choose a general and technological pathway or a vocational pathway.

To fulfil the aim of this study, four research questions were designed to guide this study:

RQ1: What is the effect of interactive simulations based on the 5E learning model on students' attitudes toward physical science?

RQ2: Do interactive simulations based on the 5E learning model have a significant impact on student performance in physics?

RQ3: Is there a gender difference in attitude toward physics before and after using interactive simulations?

RQ4: Is there a relationship between students' attitudes toward physics and their school performance before and after using interactive simulations?

2. Research method

2.1. Design study

The study followed a quasi-experimental design in which students were divided into two groups (see Table 1). Two data collection instruments were used: the first was an attitude test conducted before (pre-test) and after (post-test) students participated in interactive physics learning simulations. The second instrument was a physics performance test, also administered as both a pre-test and a post-test. This experimental study was conducted with third-year students (four classes) of a public middle school in Morocco over 10 weeks in March, April, and May 2023 (second semester). The physics lessons were held once a week, with each session lasting two hours. Students were randomly selected to participate in this study. To limit the possible effect of the teacher, the same physics teacher, who holds a master's degree in physics chemistry teaching profession and has 12 years of experience, taught the second-semester curriculum topics to the students. Table 2 shows some of the second-semester physics curriculum content.

Table 1

The research design

Group	Pre-test	Application	Post-test
Experimental	physics performance test pre-attitude	Taught by simulations for 10 weeks	Performance test Post-attitude
Control	physics performance test pre-attitude	Taught by the conventional method for 10 weeks	Performance test Post-attitude

Table 2

Middle school physics curriculum

Topic	Content
Mechanics	Concept of force – Weight and mass
Electricity	Electrical resistance – Ohm's law Electrical energy

2.2. Participants

A total of 127 students from four third-year classes at a middle school in Meknes, Morocco, participated voluntarily in this study during the 2022-2023 school year. Among the students, 63 (49.6%) were boys and 64 (50.4%) were girls. All participants were aged between 14 and 16 years. Table 3 illustrates the distribution of students by gender in each group.

Table 3

Distribution of students in groups by gender

Gender	Groupe experimental		Groupe control	
	Frequency	Percent	Frequency	Percent
Female	33	53.2	31	47.7
Male	29	46.8	34	52.30
Total	62	100	65	100

2.3. Data collection tools

Two instruments were used in this research: the Physics Performance Score and the Physics Attitude Scale (ATP). Both instruments are briefly outlined below.

Physics performance score. The students' performance scores were collected from their results in physics over the two semesters of the 2022-2023 school year. The score obtained in the summative assessment at the end of the first semester, before the implementation of the study, was used as a pre-test to evaluate and compare the students' initial levels in physical science. After completing the study (at the end of the second semester), a new summative assessment (post-test) was administered to assess whether there was a significant difference in students' performance in physics after the experimental process. The content of the summative assessments was based on the official physics curriculum for the third year of middle school. Each summative assessment includes multiple-choice questions, open-ended questions, and a problem-solving exercise

Each summative assessment was validated by two physics teachers and a physics inspector. Additionally, to verify the reliability of the test items, a performance post-test was administered to 35 students who had not participated in the study. Test reliability was assessed by calculating Cronbach's alpha, which yielded a value of 0.780, indicating good item reliability.

Physics attitude scale. To evaluate changes in students' attitudes toward physical science, an Attitude Towards Physics (ATP) questionnaire developed by Kaur and Zhao (2017) was administered before and after the implementation of the study. This attitude questionnaire contains more focused scales to measure the underlying constructs of attitude towards physics among middle school students. The ATP was reduced from 60 to 45 items (25 positive, 20 negative) after the content validity of the scale was reviewed by experts, including two teachers and a physical science educational inspector. It consisted of five variables: Enthusiasm for physics (7 items), Learning physics (11 items), Physics as a process (8 items), Physics teacher (11 items), and Physics as a future vocation (8 items).

The ATP is a five-point Likert-type scale, and positive questions are scored as follows: Strongly Agree is assigned a score of 5, Agree is scored as 4, Neutral is scored as 3, Disagree is scored as 2, and Strongly Disagree is scored as 1. For negative questions, the scoring system is reversed. The scale's maximum and minimum scores are 225 and 45, respectively. The ATP was tested with a different group of 35 third-year middle school students to check the readability of the questions.

The Cronbach's alpha value of the test group was found to be acceptable at 0.778. In the general study, the reliability coefficients were calculated to be 0.782 for the attitude pre-test and 0.79 for the attitude post-test.

2.4. Research procedure

After receiving approval from the Provincial Directorate of National Education in Meknes and permission from the school director to use the computer room, we collected the notes of physical science students from the first-semester summative assessment to determine their pre-test performance. We then informed the students that the session would be conducted in an academic environment following ethical guidelines. We emphasized that participation was voluntary and anonymous. Before beginning the study, an attitude pre-test was administered to both groups of students. We took the time to explain each question individually and answered any questions the students had.

For the experimental group, physics experiments were taught to students using interactive simulation activities on the topics of “*electricity*” and “*mechanics*”. PHET simulations built by the University of Colorado, PCCL from a private company, and eduMedia (an educational website specializing in the creation of digital content) were used based on the 5E model of teaching, which consists of five phases.

During the Engage phase, the teacher asked the students questions to check their prior knowledge and reveal their conceptions. Additionally, the teacher stimulated their interest and curiosity by presenting the concepts of mechanics and electricity in an integrated and relevant manner. In the Explore phase, students studied and explored concepts in groups using interactive simulations, either autonomously or with guidance. In the Explain phase, the teacher provided explanations and clarifications to help students understand the concepts and encouraged them to make connections with their prior knowledge. In the Elaborate phase, the teacher challenged students’ conceptual understanding and skills while students applied their understanding to real-world situations or new experiences. Finally, in the Evaluate phase, students demonstrated their learning through assessments or other activities using interactive simulations.

The control group was taught physics experiments using a conventional method, which mainly involved conducting laboratory experiments described in the textbook. The teacher usually played a central role in demonstrating the experiment and guiding students through the process. Students typically worked in groups or pairs and recorded their observations and results, which they then discussed with the teacher and their peers.

Then, the students took a pre-attitude test. Finally, we administered a summative assessment to the students as a post-test for performance. This assessment focused on the content taught during the study. Table 4 shows some of the simulations used to teach the electricity unit to the students.

2.5. Data analysis

Quantitative data generated from the administration of the ATP questionnaire and performance test were collated and analyzed using SPSS version 24 to conduct descriptive and parametric statistical analyses. Descriptive statistics were used to analyze mean attitude scores before and after the tests, which included both a pre-test and a post-test.

To determine if the pre-test and post-test attitudes in the two groups followed a normal distribution, we used the Kolmogorov-Smirnov normality test, as presented in Table 5.

Table 4

Examples of the simulations used to teach students

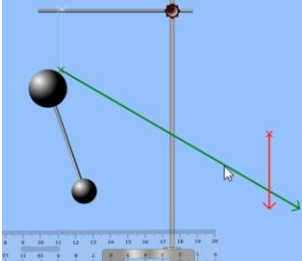
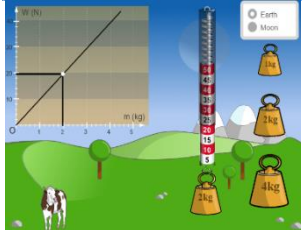
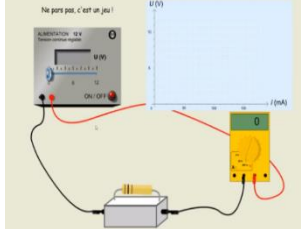
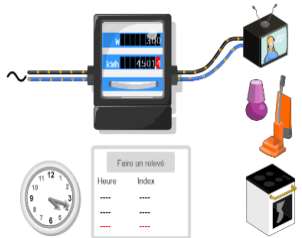
Unit	Name of the simulation	The screenshot of the simulation	Description of simulation
Mechanics	Representation of forces		The simulation allows students to represent and model forces.
	Weight / Mass		This simulation allows students to: Distinguish between weight and the mass of an object (fundamental property of the object in Kg). To simulate the influence of the gravitational constant on the force.
Electricity	Ohm's law		The simulation allows students to trace the characteristic curve of an ohmic conductor, involving measurements, unit selection, scaling, point placement, curve tracing, and formulation of the law of proportionality.
	Power consumption		The simulation allows students to know how to interpret an electric bill and how to read an energy label.

Table 5

Normality test of pre-/post-test attitudes and performance for the two groups

		Kolmogorov-Smirnov			Interpretation
	Group	Statistic	df	Sig.	
Pre-attitude	Experimental	0.093	62	0.200*	Normally distributed
	Control	0.106	65	0.066	
Post-attitude	Experimental	0.092	62	0.200*	
	Control	0.087	65	0.200*	
Pre-performance	Experimental	0.069	62	0.200*	
	Control	0.076	65	0.200*	
Post-performance	Experimental	0.080	62	0.200*	
	Control	0.091	65	0.200*	

Note. *** $p < .001$; ** $p < .01$; * $p < .05$

According to Table 5, the significance values for both groups in the pre-test and post-test for attitude and performance are greater than 0.05, indicating that the data follow a normal distribution. Therefore, we used parametric statistics, including a paired-sample *t*-test and Student's *t*-test, to determine whether the mean differences observed were statistically significant. The Pearson rank correlation coefficient test was used to examine the strength of the relationship between students' attitudes and their performance.

3. Results

3.1. Students' attitudes toward physical science

To evaluate the impact of using interactive simulations in teaching physical science on students' attitudes toward physics, we used the ATP attitude scale as a pre-test and post-test to assess the attitude levels of all participating students, who were divided into two groups. We calculated mean scores for each variable, including enthusiasm for physics, learning physics, physics as a process, the physics teacher, and physics as a future vocation. These scores were categorized as low, medium, or high based on the mean score, as shown in Table 6. Fig.1 provides a summary of students' mean scores across the five factors of attitude toward physics.

Table 6

Level of variables

Mean Scores	Level
1.00 – 2.33	Low
2.34 – 3.66	Medium
3.67 – 5.00	High

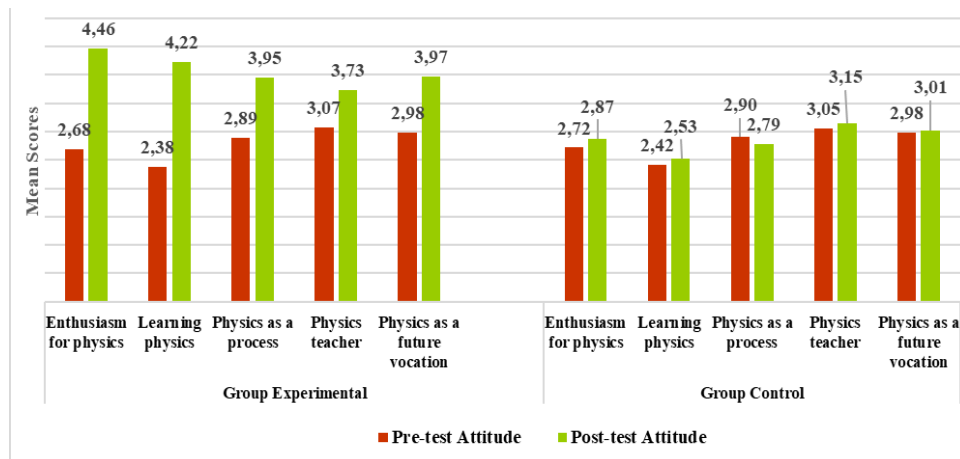


Fig. 1. The mean score of students' attitudes toward physics for both groups

Fig.1 illustrates the total attitude scores in each dimension, distributed by the two groups. Before the study, students in both groups had medium pre-attitude scores across all variables. The figure indicates that there was no significant change in the post-attitude

scores of the control group. However, the use of interactive simulations led to an increase in mean scores across all variables for the experimental group, with each variable achieving a high score. Table 7 presents the results of this comparison.

Table 7

Pre and post-test results for experimental and control groups

	Group	M	Attitude	SD	<i>t</i>	<i>df</i>	Sig.
Pre-test	Experimental	125.80	Medium	10.07	-.252	125	.801
	Control	126.26	Medium	10.23			
Post-test	Experimental	182.00	High	8.61	22.84	125	.000***
	Control	129.03	Medium	16.20			

Note. *** $p < .001$; ** $p < .01$; * $p < .05$

According to Table 7, the pre-test results show that the mean attitude scores of the two groups are similar. The experimental group recorded a mean score of $M = 125.80$ with a standard deviation of $SD = 10.07$, while the control group recorded a mean score of $M = 126.26$ with a standard deviation of $SD = 10.23$. Both groups had a “medium” level of attitude before the intervention. An independent sample *t*-test was conducted to compare the pre-test attitude scores of the two groups. The *t*-test yielded a *p*-value of $0.801 > 0.05$. This indicates that there is no significant difference in the pre-test attitude scores between the experimental and control groups, indicating that both groups started with equivalent attitudes before the study commenced. For the post-test attitude scores, the experimental group recorded a mean score of $M = 182$ with a standard deviation of $SD = 8.61$, which is classified as “high”, whereas the control group obtained a mean score of $M = 129$ with a standard deviation of $SD = 16.20$, classified as “medium”.

The results of the independent sample *t*-test for the post-test scores revealed a highly significant difference between the two groups, with a *p*-value of $p = 0.000 < 0.05$. This significant *p*-value indicates that the experimental group had a significantly more positive attitude compared to the control group after the intervention. These results demonstrate that the use of the 5E-based simulation had a substantial impact on improving the attitudes of students in the experimental group.

To evaluate the change in attitudes within each group from pre-test to post-test, a paired *t*-test was performed. This test provided information on the changes that occurred within each group before and after the intervention. Table 8 presents the results of this analysis.

Table 8

Paired-sample *t*-test for pre-test and post-test scores of attitudes toward physics

Group	Measurement	MD	<i>t</i>	<i>df</i>	<i>p</i>
Experimental	Post-test – pre-test	56.19	42.760	61	0.000***
Control	Post-test – pre-test	2.77	1.181	64	0.242

Note. *** $p < .001$; ** $p < .01$; * $p < .05$

The results presented in Table 8 show a significant difference between pre-and post-test attitude scores within the experimental group. The mean difference (MD) is 56.19, with a *t*-value of 42.760 and a *p*-value of $0.000 < 0.05$. This indicates a statistically significant improvement in student attitudes in this group after the use of interactive

simulations. In contrast, the control group showed no significant difference in their pre-test and post-test scores, with a mean difference (MD) of 2.77, a t -value of 1.181, and a p -value of 0.242, which is greater than 0.05. This means that there was no significant improvement in attitudes in the control group.

3.2. Attitude toward physical science based on gender

A parametric test (independent t -test) was used to determine if there was a significant difference in attitudes toward physical sciences between girls and boys in the experimental group. The distribution of data for girls and boys in both the pre-test and post-test attitudes is normalized. Table 9 shows the result of the independent t -test.

Table 9

Result of the independent t -test (pre-test and post-test of attitude)

	Gender	N	M	SD	t	p
Pre-test attitude	F	33	125.49	6.77	-0.266	0.791
	M	29	126.17	12.98		
Post-test attitude	F	33	182.63	8.57	0.617	0.539
	M	29	181.27	8.76		

Note. *** $p < .001$; ** $p < .01$; * $p < .05$

Table 9 shows that the mean pre-test attitude score for girls is $M = 125.49$ ($SD = 6.77$), while for boys it is slightly higher, at $M = 126.17$ ($SD = 12.98$). The p -value ($p = 0.791 > 0.05$) indicates that there is no statistically significant difference between the pre-test attitudes of girls and boys. In other words, before the intervention, both gender groups exhibited similar attitudes towards physics.

For the post-test, the mean score for girls is $M = 182.63$ ($SD = 8.57$), and for boys, it is $M = 181.27$ ($SD = 8.76$). Again, the p -value ($p = 0.539$), greater than 0.05, indicates that there is no statistically significant difference between the post-test attitudes of girls and boys after the use of interactive simulations.

3.3. Comparison of the pre-and post-performance between groups

Table 10 shows no significant difference in pre-test performance scores between the experimental and control groups ($p = 0.670 > 0.05$), indicating that both groups had a similarly low level of knowledge before the intervention, with a mean score below $M = 11$. This ensures that any difference observed at the post-test is probably due to the intervention and not to an initial difference in level. However, a significant difference was observed in the mean post-test performance scores between the two groups, favoring the experimental group ($p = 0.000 < 0.05$) (see Table 10). This suggests that simulations based on the 5E model are more effective than the current curriculum in increasing student performance in physical science.

To compare the increase in student performance in the experimental group, we conducted a paired t -test on the pre-and post-test scores, which followed a normal distribution.

Table 10

Comparison of the pre- and post-performance between groups

	Group	M	SD	<i>t</i>	<i>p</i>
Pre-test	Experimental	10.67	2.81	4.27	.670
	Control	10.45	2.93		
Post-test	Experimental	13.19	3.60	3.63	.000***
	Control	11.10	2.85		

Note. *** $p < .001$; ** $p < .01$; * $p < .05$

Table 11 shows no significant increase in the performance of the students in the control group ($MD = 0.65$, $p = 0.137$). However, the mean difference in post-performance scores in the experimental group ($MD = 2.52$) was higher than the mean difference in the control group. Since the p -value was less than 0.05 ($p = 0.001$), this indicates a significant difference in students' scores before and after the use of interactive simulations. This suggests that the interactive simulations based on the 5E model were effective in improving students' learning outcomes in physical science.

Table 11Paired sample *t*-test results for pre-and post-performance

Group	Measurement	MD	<i>t</i>	<i>df</i>	<i>p</i>
Experimental	Post-test pre-test	2.52	5.432	61	0.000***
Control	Post-test pre-test	0.65	1.507	64	0.137

Note. *** $p < .001$; ** $p < .01$; * $p < .05$

3.4. Student performance based on gender in group experimental

The performance scores of the students are presented in Table 12.

Table 12

Student performance based on gender in pre-/post-performance

	Gender	N	M	SD	<i>t</i>	<i>p</i>
Pre-test	F	33	10,62	2,29	-.131	0.890
	M	29	10,72	3,34		
Post-test	F	33	13,54	3,39	0.805	0.424
	M	29	12,80	3,84		

Note. *** $p < .001$; ** $p < .01$; * $p < .05$

According to Table 12, the average pre-performance score for girls was 10.62, while for boys it was 10.72. In the post-performance test, the average score for girls was 13.54, while for boys, it was 12.80. A Student's *t*-test was carried out to determine whether the difference between girls' and boys' scores in the pre- and post-performance tests was significant. The results of the *t*-test (see Table 12) showed no significant difference between girls and boys in the pre-performance test ($t = -0.131$, $p = 0.890$), suggesting that girls and boys had similar fundamental knowledge of physics before participating in this study. In the post-performance test, there were still no significant differences between girls

and boys ($t = 0.805$, $p = 0.424$). This indicates that using interactive simulations to teach the unit on electricity and mechanics did not favor one gender over the other.

3.5. The relationship between students' attitudes about physics and their performance in the experimental group

This section of the analysis examined the correlation coefficient r between students' attitudes toward physics and their performance before and after using the interactive simulations. The details of the r are presented in Table 13, and the strength of the correlation can be interpreted using the scale suggested by Wuensch (1996). Table 14 provides the interpretation of the Pearson correlation r .

Table 13

Relationship between students' attitude toward physics and their performance

	Pearson correlation	Sig. (2-tailed)	<i>N</i>
Pre (Attitude-performance)	0.319*	0.012*	62
Post (Attitude- performance)	0.618**	0.000***	62

Note. *** $p < .001$; ** $p < .01$; * $p < .05$ (2-tailed)

The correlation coefficient r obtained for performance and attitude toward physics before using the simulations is 0.319 (refer to Table 13 above). This indicates a weak relationship between them (see Table 14). The p -value ($= 0.012$) < 0.05 indicates that this relationship is statistically significant. The positive correlation coefficient indicates a positive relationship between students' attitudes toward physics and school performance. This means that before the use of interactive simulations, there was a weak but positive correlation between students' attitudes towards physics and their performance.

Table 14

Interpretation of the Pearson correlation r

Value of r	Interpretation
± 0.80 to ± 1.00	Very strong relationship
± 0.60 to ± 0.79	Strong relationship
± 0.40 to ± 0.59	Medium relationship
± 0.20 to ± 0.39	Weak relationship

4. Discussion

This study aimed to investigate changes in third-year middle school students' attitudes toward physics and to explore the relationship between these attitudes and their performance before and after using interactive simulations based on the 5E learning model. To accomplish this, a quasi-experimental design was employed, dividing students into experimental and control groups. The experimental group was taught using interactive simulations based on the 5E learning model, while the control group was taught the same concepts using traditional methods over ten weeks. Pre- and post-test attitudes and performance were used to compare students' attitudes and performance before and after the implementation of the study.

The results revealed that the use of interactive simulations based on the 5E learning model had a significant impact on the attitudes of students in the experimental group towards physics. After the intervention, this group recorded a marked increase in their mean attitude score from “*medium*” to “*high*”, with a post-test score of 182.00. Conversely, the attitude of students in the control group remained stable at a “*medium*” level, with a post-test score of 129.03, which is very similar to their initial score. These results suggest that the use of interactive simulations based on the 5E model significantly improved the attitudes of students in the experimental group. The substantial improvement in the experimental group’s attitude scores can be attributed to the effectiveness of the 5E model, which engages students and facilitates active participation in physics classes by simplifying abstract concepts and making them visually understandable. The simulations helped students feel more comfortable and happier during practical activities. This positive learning environment likely contributed to the significant improvement in their attitudes towards physics. The improved attitudes can be attributed to the interactive nature of the simulations, which makes abstract concepts more tangible and engaging. The 5E model further supports this by structuring learning in a way that builds on prior knowledge and encourages active exploration. These findings are consistent with several studies that have found positive changes in students’ attitudes toward science when using computer simulations in teaching (Chen & Howard, 2010; Tüysüz, 2010). Sarı et al. (2017) demonstrated an increase in the attitudes of Grade 11 science students in the experimental group who were taught through computer simulations using the 5E teaching model. However, it is important to note that not all studies have reported significant improvements in attitudes with the use of simulations. For example, Faour and Ayoubi (2018) found no significant difference in 10th-grade students’ attitudes toward physics after using PhET simulations. This discrepancy could be due to various factors, such as differences in the implementation of simulations, the subject matter, or the specific characteristics of the student population.

Additionally, no significant differences were observed between boys’ and girls’ attitudes toward physics either before or after the intervention, suggesting that this pedagogical tool is effective regardless of gender. This result is consistent with previous studies that have shown no significant difference in attitudes toward physics between girls and boys (Olasehinde & Olatoye, 2014; Sofiani et al., 2017). This suggests that there is no significant gender disparity in attitudes before using simulations. However, these results contradict those of Fatoba and Lawrence (2014), who observed a slight difference in favor of girls in students’ physics attitudes. Additionally, the results of Chen and Howard (2010) demonstrated that boys had a more positive attitude toward scientists than girls. Similarly, in the post-test attitude, there was no statistically significant difference in attitudes towards science between girls and boys ($t = 0.617$, $p = 0.539$), suggesting that the interactive simulations do not discriminate based on gender. This result is consistent with the findings of a study carried out by Kattayat et al. (2016), which indicated that there is no gender difference in the relationship between simulation-assisted instruction and attitudes toward physics. In contrast, Chen and Howard (2010) found that male students held more positive attitudes toward science than female students.

Another major finding of this study was that there was no difference between the two groups, ensuring that the study started on an equal footing. However, after the intervention, a significant difference in favor of the experimental group was observed. These results are generally in line with the findings of a previous study (Antonio & Castro, 2023), which demonstrated that the use of PhET and Crocodile Physics simulations improves students’ academic performance in topics related to electricity and magnetism.

Another study conducted by Al-Mashaqbeh (2014) suggests that the use of Computer Simulation Instruction (CSI) led to an improvement in the achievement of the experimental group. This was evident in the positive impact it had on the students' ability to conduct chemical experiments and gain a better understanding of chemical concepts. Additionally, a study by Lau and Lam (2017) investigated the science performance and teaching methodology of the ten regions with the highest PISA 2015 ratings and found that using interactive applications has the strongest correlation with performance. Furthermore, Çetin (2018) reported that using simulations based on the 5E learning model improved students' physics results compared to traditional learning methods. On the other hand, the results of this study do not align with some previous research (Quinn et al., 2009; Tsihouridis et al., 2013). This discrepancy can be attributed to several factors, including the types of simulations utilized, the total number of participants, and the statistical analysis approach.

Furthermore, the results show that girls' and boys' performance was equivalent before and after using interactive simulations based on the 5E model. This may be attributed to the fact that these simulations provide an engaging learning environment accessible to all students, regardless of gender. These findings are consistent with those of Nkemakolam et al. (2018), who also reported no significant gender differences in student achievement when using similar teaching methods. The interactive simulations based on the 5E model engaged students equally, regardless of gender, facilitating their understanding and participation in physics classes. The student's comfort and enjoyment during practical activities likely contributed to their improved performance student's. In contrast to some research, such as the TIMSS 2019 study, which found that girls perform better than boys in science. Additionally, Fu et al. (2007) demonstrated a significant difference in performance favoring girls. Therefore, girls are generally more efficient than boys. This contrast in this study might be attributed to variations in pre-performance tests (first-semester results), grade level, and school zone chosen.

Finally, our results show an interesting development in the relationship between students' attitudes toward physics and their performance after using interactive simulations based on the 5E model. Before the intervention, although there was a weak correlation between these two variables, the use of these simulations strengthened this relationship, making it much more significant after the intervention. This suggests that positive attitudes can be an important factor in students' success in physics, especially when teaching methods promote active learning and a concrete understanding of concepts. These findings are consistent with those of Tanti et al. (2021), who reported that students with a positive attitude toward science tend to perform better in the subject. In addition, Kattayat et al. (2016) showed a positive and significant correlation between adolescent students' performance in physics and their attitude towards physics after simulation-assisted instruction. However, these results contradict the findings of Ibrahim et al. (2019), which found no impact of students' attitudes toward science on their performance, indicating that students could achieve good marks in science without a positive attitude.

5. Conclusion

The data analysis results indicate that interactive simulations based on the 5E model are more effective than the conventional method. These simulations have been shown to not only improve students' performance but also enhance their attitudes toward physics. Their effectiveness stems from their ability to help third-year students better grasp key concepts in mechanics and electricity. Moreover, our study revealed a significant positive correlation

between students' attitudes toward physics and their performance in the subject. Interactive simulations in physical science instruction reinforce this relationship, as students with more positive attitudes toward physics tend to achieve higher marks. Additionally, the data reveal no significant difference between boys' and girls' attitudes toward physics, both before and after the intervention.

6. Limitations and future orientations

Overall, this study offers valuable information on the effectiveness of using interactive simulations based on the 5E model in teaching physical science to middle school students. However, several limitations should be considered in future studies to improve the generalizability and reliability of the results.

First, the sample size of this study was limited to 127 third-year middle school students. Future research should consider using a larger sample size from different grade levels to increase the generalizability of the findings.

Second, the study only focused on the topics of electricity and mechanics. Further research is needed to investigate the effectiveness of interactive simulations in teaching other scientific disciplines, such as mathematics, technology, and life and earth sciences.

Finally, although the study was conducted over 10 weeks, this may not be enough to fully explore the potential of interactive simulations in teaching physical science. Future research should consider extending the study period and providing more opportunities for practical experiments using interactive simulations.

By addressing these limitations, future research can further advance our understanding of the effectiveness of interactive simulations in science education and provide more robust evidence for their use in classrooms.

7. Ethics statement

It is commendable to hear that ethical precautions were taken into consideration during the study. Obtaining permission from relevant authorities, such as the Provincial Director of National Education in Meknes and the school principal, is a crucial step in conducting ethical research. Additionally, participants were informed of the study's objectives and that the sessions would take place in an academic environment that respects ethical principles. They were also notified that the results of the study could be published in a scientific journal. We emphasized that their participation was strictly voluntary and anonymous, ensuring that their responses would be treated confidentially. All responses to the survey were coded to generate anonymous data, without any information that could identify the names of the students participating in the study.

Author Statement

The authors declare that there is no conflict of interest.

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