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ENHANCING THE LEARNING OF NEWTON'S SECOND LAW OF MOTION USING COMPUTER SIMULATIONS

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Abstract. *This quasi-experimental study was conducted in two secondary schools in a major city in the United Arab Emirates (UAE) to examine the impact of Computer Simulations (CSs) on students' learning of Newton's Second Law of Motion (NSLOM) in grade 11 compared to traditional face-to-face education. The study used Newton's Second Law of Motion Achievement test (NSLMAT) as a pre and post-test to collect the data. Altogether 90 students aged 16-17 (grade 11) participated in this study. Two grade 11 girls' classes (40 students) and two grade 11 boys' classes (50 students) were chosen randomly to participate in this study. Descriptive and Inferential statistics were used to analyze data. Results showed that CSs, through visualization, aided in establishing connections and brought attention to the concepts and details of NSLOM. In addition, CSs yielded better results than those taught in face-to-face education. The Results also suggest that CSs greatly impacted both female and male students. CSs helped female and male students gain a better understanding of NSLOM topics. The study recommended that physics teachers integrate CSs into their teaching and use them as valuable tools to improve student learning outcomes.*

Keywords: *computer simulations, United Arab Emirates, Newton's Second Law of Motion, students' performance*

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Introduction

Physics has been viewed by many, including students, as a challenging subject. This is likely due to the abstract nature of many of its concepts and the mental effort required to grasp them fully. Learning physics meaningfully requires students to perform multiple representations that be completed and processed simultaneously, including experiments, formulas, computations, charts, and conceptual explanations. The negative image of Physics has been and continues to concern both students and teachers (Erinosho, 2013; Jimoyiannis & Komis, 2001). The problem comes from its perceptions among students and teachers as complex and difficult to comprehend (Alexanian, 2013; Bajpai, 2013; Radlović-Čubrilo et al., 2014; Stern et al., 2017). Recent trends in teaching and learning suggest that the solution to this negative image of physics relies on discovering new, efficient teaching strategies that preserve student achievement and improve student attitudes (Alarabi & Alwardat, 2021; Balfakih, 2003; Tairab et al., 2020). It was also noted that students could only enhance their understanding of fundamental physics concepts by implementing engaging educational techniques, such as visual representations and models (Alsalhi et al., 2022; Hamad et al., 2022; Tawil & Dahlan, 2017; Wardat et al., 2022).

On the other hand, Sirait and Mursyid (2018) suggested that what makes Newton's laws and other physics concepts so difficult to grasp because they are tied to other fundamental concepts like velocity and acceleration, which students must first understand before attempting to fathom Newton's Second Law of Motion (NSLOM). Furthermore, Obaidat and Malkawi (2009) found that most students might have alternative and naïve models of basic concepts of kinematics and Newton's laws of motion, which in turn might have led to difficulties in solving physics problems (Camarao & Nava, 2017; Sirait & Mursyid, 2018; Tairab et al., 2020).

In most UAE schools, face-to-face education is the primary mode of physics education (the method that relies on teacher-centered and guided

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approaches to learning such as lectures, recipe laboratory activities, and student-made observations outside of the classroom with little or no interactive engagement). Previous studies have demonstrated that when using Computer Simulations (CSs) as a teaching technique for investigating those concepts, students are likely to acquire a more meaningful knowledge of abstract physics concepts (Zacharia & Anderson, 2003). To eliminate the difficulties and misconceptions about students' learning outcomes when teaching NSLOM, simulations in science classrooms could potentially improve diverse students' access to high-quality learning experiences (National Research Council, 2011, p.67).

A computer simulation is a program that recreates the natural world in a digital setting by letting the user alter the parameters of a scientific model of the natural or physical world (D'Angelo et al., 2014; Holec et al., 2004; Wilson, 2016). CSs play a significant role in science education. For example, using CSs to teach physics concepts can enhance students' understanding by providing a level of reality that would not be possible with traditional teaching methods (Mengistu & Kahsay, 2015). Podolefsky et al. (2010) found that CSs significantly improved students' understanding of basic concepts that are difficult to understand. Moreover, compared to non-simulated education, CSs have also impacted the overall achievement in physics (D'Angelo et al., 2014; Jarrah et al., 2020; Smetana & Bell, 2012).

Based on the evidence mentioned in previous research (Bagnoli et al., 2018; Camarao & Nava, 2017; Erinosho, 2013; Martin et al., 2015; OECD, 2015; Ornek et al., 2008; Sarı & Madlazim, 2015; Sari et al., 2019), it seems that there is a need to improve student learning of physics by overcoming the difficulties students face in learning physics. The Ministry of Education (MOE) of the United Arab Emirates (UAE) recommended that physics teachers improve their educational methods to make physics more attractive and less abstract. It also proposed that teachers should actively involve students in the teaching and learning to encourage meaningful learning (Aloufi et al., 2021; MOE, 2000; Sahoo, 2016, cited in Ridge et al., 2015).

Research Problem

Despite the importance of physics and physics education, a coherent and meaningful understanding of physics concepts such as (NSLOM) is still a problem for educators. Physics education resources utilized in classrooms and laboratories are difficult to manipulate and unappealing to many students (Cairns & Areepattamannil, 2019; Jarrah et al., 2022; MOE, 2000; Sahoo, 2016, cited in Ridge et al., 2015; Next Generation Science Standards, 2013; Wardat et al., 2022; Wilson, 2016).

On the other hand, it has been documented that Emirati students are experiencing difficulties in physics which are attributed to ineffective educational strategies and a lack of motivation (Tawil & Dahlan, 2017). In most UAE schools, the primary mode of physics education is mostly of traditional focus in terms of educational strategies and learning environment. It focuses on teaching content and formulas to solve common problems (Balfakih, 2003; Hussein & Reid, 2009). A step towards comprehending physics better might be the integration of CSs in teaching as an appropriate alternative to remedy this problem and improve students' learning. This is because CSs have shown great potential to stimulate knowledge and interest. They may enable learners to recognize and interact with natural phenomena, promote learners' challenges, and prompt reactions (National Research Council, 2011). The present study is, therefore, a response to the call for researchers for further research on the effectiveness of CSs in teaching physics (Hadzigeorgiou et al., 2017; Jimoyiannis & Komis, 2001; Radlovic-Cubrilo et al., 2014; Tashtoush et al., 2022). Considering that the use of CSs as an educational tool is still in its infancy in UAE schools, the findings of this study may contribute to our knowledge of the impact of CSs in the UAE context. Thus, it may attempt to fill the research gap on the efficacy of CSs in teaching physics, specifically NSLOM, at the secondary school level in the UAE context.

Research Aim and Research Questions

This study was designed to assess the possible impact of computer simulations on Emirati grade 11 learning of NSLOM. Specifically, the study attempted to determine grade 11 physics students' overall performance in NSLOM when taught with CSs compared to traditional face-to-face education. Therefore, to explore the impact of CSs on the Emirati students' learning of NSLOM, this study addressed the following research questions:

- What impact do computer simulations have on grade 11 students' performance in Newton's second law of motion?

- Are there any statistically significant differences in performance in Newton's second law of motion between grade 11 students who learned through CSs and those who learned through traditional face-to-face education?
- Are there any statistically significant gender differences in performance in Newton's second law of motion between grade 11 students who learned through CSs and students who learned through traditional face-to-face education?

Research Significance

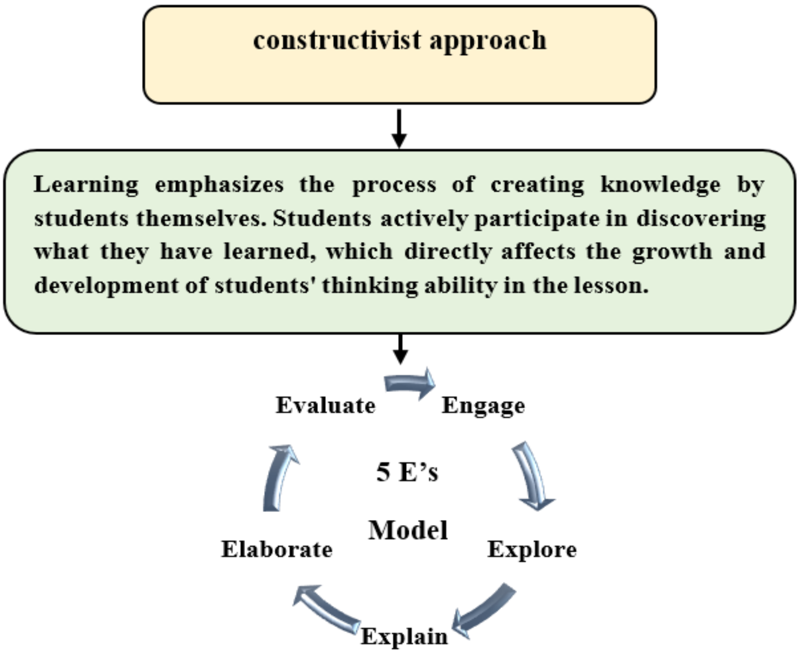
The results of this study could be helpful and supportive to physics teachers and other stakeholders responsible for adapting and modifying the curriculum. The results may provide physics teachers with opportunities to address physics teaching more meaningfully by identifying difficulties students often encounter. It may also help students develop a higher-order understanding because of the visualization perspectives CSs provide. Similarly, CSs may also provide a shift toward effective student-centered pedagogy, which in turn may affect the role of teachers to become more productive than being mere knowledge disseminator, to becoming a facilitator who focuses on teaching students how to think critically and how to make effective use of educational resources to learn new information. Kattayat et al. (2016) suggested that when teachers integrate CSs into classroom education, students will likely develop a positive attitude towards physics. As an outcome of these positive attitudes, students may probably achieve better results in physics. Finally, the study findings could also attract stakeholders' and curriculum developers' attention to the effects of technology integration in creating opportunities for active science learning through infusing hands-on activities. This integration can be achieved by dedicating more learning activities through CSs when teaching general science and physics.

Literature Review

Theoretical Framework

The theoretical framework of this study is based on the constructivist approach (Figure 1).

Figure 1
The Theoretical Framework of this Study



According to the constructivist approach, education must enable learners to actively participate in knowledge construction and the learning processes (Hirshman & Bjork, 1988; Philips, 1997). The 5E learning cycle is a model designed to promote inquiry-based learning. Each "E" is part of the process that helps students arrange learning experiences to create a link between previous knowledge and new concepts (Sarı et al., 2017). 5E's consist of five stages (see Table 1). These are: Engage, Explore, Explain, Elaborate, and Evaluate.

Table 1

Summary of the 5E Instructional Model, Adapted from Lo (2017)

Phase	Description
Engagement	Teachers use learning activities to promote students' curiosity and activate their prior knowledge required for learning the new topic.
Exploration	Students gain experiences related to the learning items through activities such as preliminary investigations. Based on students' experiences in the engagement.
Explanation	Teachers introduce new knowledge and skills to their students.
Elaboration	Teachers reinforce students' understanding and improve their skills by offering additional activities. Students have to apply what they learned to solve novel problems.
Evaluation	Students assess their understanding and ability. Meanwhile, teachers evaluate students' learning progress and their learning outcomes.

Through visualization, CSs help establish contacts and attract attention, and this, in turn, enables students to become active participants. The ability to interact with and manipulate variables or study context in general and repeat situations can prove predictions consistently in parallel to classroom discussions (Konicek-Moran & Keeley, 2015). furthermore, it provides various tools to support students in ways that allow them to construct their knowledge, leading to efficient learning and meaningful learning outcomes (Husain, 2010).

CSs are an effective learning tool because they integrate graphics and animation, allowing students to experience nuanced processes and procedures (Husain, 2010; Stieff et al., 2005). In other words, CSs create a unique way of visualizing phenomena and allow users to interact with the dynamics of the model system (Srisawasdi & Panjaburee, 2015). This is due to the ability of the CSs to imitate reality as closely as possible in the tiny world and contain genuine connections with many real-world events (Stieff et al., 2005).

Computer Simulations and Physics teaching

Previous research studies have shown that using CSs education as a teaching approach provides better results than traditional education, particularly in students' attitudes, scientific knowledge, and achievements (Bakaç et al., 2011; Kattayat et al., 2016). Rutten et al. (2012) reviewed empirical studies on the effects of CSs on science education in the past decade focusing on two issues: the use of CSs to enhance traditional education and how best to use CSs to improve the learning process. Rutten et al. (2012) reported that CSs could improve traditional teaching, especially in laboratory activities. These findings corroborate those of Bozkurt and Ilika (2010), who found that students taught using the CSs approach outperformed those not taught via the CSs approach.

Many researchers have argued that there is ample evidence that CSs such as PhET interactive simulations can be a powerful tool for students to learn science, as their design has an intuitive interface for students with minimal text (Adams, 2010; Batuyong & Antonio, 2018; Keller et al., 2007). For example, in Indonesia, Eveline et al. (2019) found that PhET simulation learning using the scaffolding method impacts students' learning independence. These results indicated that, in high school, the PhET simulation scaffolding method could be used to enhance student autonomy in learning.

In summary, research studies on physics education have found that the use of CSs, encouraged not only active learning of scientific content but also improved education, met the students' learning styles and personal needs,

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improved achievement in the field of physics, and supported different types of students (such as visually oriented students) (Kattayat et al., 2016; Mengistu & Kahsay, 2015). Moreover, researchers suggested that CSs can be used as an accessory or alternative to other forms of teaching to enhance students' understanding of physics concepts (Rutten et al., 2012). According to Podolefsky et al. (2010), teachers found that CSs significantly improved students' understanding of basic concepts that are usually difficult to understand.

Computer Simulations and Newton's Second Law of Motion

NSLOM is the central and most important topic taught in classical mechanics (Itza-Ortiz et al., 2004; Mico et al., 2010; Sirait & Mursyid, 2018). Understanding NSLOM is likely the key to understanding mechanics (Sari & Madlazim, 2015). According to the curriculum guidelines of the UAE Ministry of Education (MOE), before high school physics is over, students should be able to explain NSLOM and describe the forces acting on objects in different states of motion (Bauer & Westfall, 2011), and that for any given net force, there is a specific acceleration that the object will experience (Itza-Ortiz et al., 2004). When a net force (Fnet) acts upon an object, the resulting acceleration (a) is proportional to (Fnet) and inversely proportional to the mass of the object (m). Nevertheless, many textbooks present NSLOM so abstractly that students cannot see the relationship between force and motion (Mico et al., 2010).

Several previous studies have highlighted the positive effect of using CSs and experiment animations in improving NSLOM learning. For example, Sari and Madlazim (2015) found that Newton's second law significantly improved the conceptual ability of students who used CSs to learn compared to students who did not study with CSs.

Studies Related to the UAE Context

Although CSs are not familiar with the UAE context, virtual learning is one of the recent trends within schools in the UAE. This is a significant trend in that the UAE will be looking forward to bringing in technologies in the form of e-learning and other forms of technologies (Aoude, 2015).

There is a scarcity of studies related to the UAE concerning using CSs in physics teaching. However, there are studies related to the impact of technology in general. Awan (2012) investigated how the use of computers/laptops influences the dynamics of the classroom setting. Martin (2013) conducted a study to determine the level of participation of Emirati higher education students in digital technologies, including the internet, and whether this level of involvement is like an international model. Alneyadi (2019) conducted a study in the UAE to explore the views of science teachers on the nature and frequency of the implementation of Virtual Laboratory (VL) by students in the UAE and their contributions to the development of science education.

The review of previous research findings revealed that very little research had been carried out on the impact of CSs on student learning in the UAE, particularly on the integration of CSs in the teaching of NSLOM. Furthermore, previous research studies did not examine the effect of CSs on students' performance, and only one study so far was found to be related to the UAE context. Aoude (2015) investigated the role of CSs on the performance of physics, focusing on conceptual and procedural knowledge of projectile motion. Therefore, the present study's findings are expected to assist in a better understanding of how CSs impact students when learning physics.

Research Methodology

Research Design

The study employed a quasi-experimental pre-test-post-test experimental and control group design Table 2. Creswell (2013) suggested that in a quasi-experimental design, causation is determined by applying a treatment or condition to one group and using the results compared to a control group. This appropriate design provides an environment for comparing the two groups based on the intervention.

Table 2
The Experiment Design Pattern

Groups	Pre-test	Treatment	Post-test
Experimental group EG	Applied	Receiving treatment CSs teaching	Applied
Control group CG	Applied	No treatment Face-to-face teaching	Applied

Data Collection Procedures

The study took place on October 30, 2019, in two schools. Each school chose two Grade 11 classes to participate in the study. Then the classes are randomly assigned to an experimental group (EG) or a control group (CG). Data collection took about one month and was collected in different stages. In the first stage, all students of the EGs and the CGs took part in a pre-test, which took about 45 minutes. The students were informed that their participation in the test was voluntary and that the result would not affect their grades. The second stage involved teaching the unit of NSLOM. The students who participated in this study had already received approximately 20 lessons and had also completed 3-lessons labs covering various physics concepts in NSLOM. The NSLOM activities sessions were administered in three separate sessions in a different week, with 45-60 minutes each. The control group conducted experiments on NSLOM in a traditional laboratory where students followed written instructions to conduct investigations and answered pre-defined and stated teacher's questions on NSLOM. On the other hand, the experimental group conducted similar experiments using CSs within an inquiry-based learning environment. In CGs, the students engaged in a hands-on activity on 'NSLOM. However, the students in EGs were expected to discover mathematical relationships of NSLOM and explain phenomena in the NSLOM simulation. Finally, the students took the same test at the end of this stage. The answers to the exam were approximately 45. The NSLMAT test was conducted in an environment of integrity to prevent any cheating or support, and the researcher explained to the students the importance of working independently.

Population and Sampling

Schools in the UAE follow the national curriculum; teaching physics begins in Grade 10 as a separate subject. Students must choose the advanced science or general streams (Balfakih, 2003). Compared to the general stream, students in the advanced stream will have more education in mathematics and science (UAEG, 2019).

In this study, the target population consisted of secondary school students aged 16-17 years (grade 11) in Al Ain city in the UAE. All schools use the same curriculum in teaching physics. In this study, two schools (out of 14 schools) were selected as purposeful convenience sampling, one for boys (taught by male teachers) and the other for girls (taught by female teachers). The criteria used to select these schools included: The grade 11 students in these schools were familiar with the content of the PhET simulations, the students shared similar demographic characteristics such as age, gender, and ethnicity, and both schools are located in one emirate in the UAE. The socioeconomic status is mainly from the middle class. Both schools equipped each student with an individual laptop and printed text in the teaching of physics. Physics lessons are taught by qualified teachers who are fluent in English. Also, the two groups are in the advanced stream in the academic year of 2019-2020.

The sample of classes was obtained using the random sampling technique. The study included four classes of students; In the girl's school, there were three Grade 11 classes (each class has 20 students); one of these three classes was randomly allocated to face-to-face education (CG), while another class was assigned to the CSs environment treatment (EG). The second school for boys has four grade 11 classes (each class has 25 students); one was chosen randomly to be a CG, whereas another class was selected to be the EG. Therefore, ninety (90) students participated in this study, of whom 50 were males and 40 females were chosen from the advanced stream. Table 3 summarizes the characteristics of the study group's participants.

Table 3
Study Groups

Groups	Gender	Number (N)	Total
Control group (CG)	Female	20	45
	Male	25	
Experimental group (EG)	Female	20	45
	Male	25	

Materials

- Physics Education Technology (PhET) Simulations Package

Physics Education Technology (PhET) is a collection of interactive computer simulations based on research that may be used to educate and learn physics, chemistry, math, and other sciences (Wilson, 2016). PhET is an open educational resource that a non-profit organization runs. It was formed in 2002 to improve science education and learning. PhET simulations are particularly beneficial for visualizing difficult-to-understand subjects in science and math while also engaging students through manipulation (Wieman et al., 2008). According to Astutik and Prahani (2018), PhET simulation is meant to present numerous charts and quantitative information windows simultaneously. The great advantage of PhET is that it can model inaccessible conditions in a real laboratory so that the process can be explored under various conditions, such as no air resistance, friction, and risk (Batuyong & Antonio, 2018; D'Angelo et al., 2014). Interactive PhET simulation is now widely used in physics teaching (Wieman et al., 2010). Adams (2010) claimed that there are several ways to use the PhET simulator in education; for example, the PhET simulations can help: present new topics, build concepts or skills, and provide final review and reflection. It also provides a common visualization between students and teachers to facilitate all communication (Perkins et al., 2014). Finally, the PhET simulation can be played online or downloaded for free, is very research-based, has interactive animation, is easy to use, and allows actions that are difficult or not to take in the real world (Batuyong & Antonio, 2018).

Research Instruments

This study used java-based NSLOM simulations available for download and installation on student computers from the website http://phet.colorado.edu., which is free to use. Students were given detailed instructions on navigating the NSLOM simulations and encouraged to experiment with the various features. Each student then performed a series of experiments using the pre-explanation provided in the NSLOM worksheet. Finally, students were asked to determine the mathematical relationships of NSLOM from graphs and visual representations.

Newton's Second Law of Motion Achievement Test (NSLMAT) included multiple choice questions that assessed students' performance in NSLOM (see Appendix A). An NSLMAT was used as a pre-test and a post-test to compare differences in performance mean scores between students in the treatment group, who learned by CSs, and their counterparts in the control group, who learned NSLOM using face-to-face education without CSs.

Validation of NSLMAT

Concerning the validity of the content, the test was presented to a group of educators, consisting of 10 experts specialized in physics and physics education, inspectors, high school teachers, and a group of university professors. The experts were asked to ensure that the test was content valid in terms of formulation of phrases and language, scientific accuracy, comprehensiveness of the measuring tool, and its suitability for the goal for which it was developed. Additionally, the experts were asked to judge the paragraphs' clarity and practicality for the study participants. The researchers obtained opinions and suggestions from the judges. In light of the observations received and after all the changes made, the final test consisted of 16 multiple-choice questions. The questions included an introduction and four alternatives, one of which is correct. Therefore, students must choose an answer from symbolic options A, B, C, and D.

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NSLMAT Reliability

NSLMAT was given to eleventh graders from the same schools. They were randomly assigned as pilot samples, did not participate in the experiment, and provided feedback on their understanding of questions related to NSLOM. Their responses indicate that they understand these questions. Split-half reliability was calculated to assess the internal consistency of this NSLMAT by comparing the odd numbers' results with the even numbers' results, as illustrated in Table 4.

Because the two parts' reliability and variances were not equal, researchers adopted the Guttman split-half reliability coefficient, and it was found to be .758, which was deemed appropriate and acceptable for this research.

Table 4
Reliability Statistics for NSLMAT Exam

Cronbach's Alpha	Part 1	Value	.741
		N of Items	16a
	Part 2	Value	.844
		N of Items	16b
	Total N of Items		32
Correlation Between Forms			.611
Spearman-Brown Coefficient	Equal Length		.759
	Unequal Length		.759
Guttman Split-Half Coefficient			.758

Data Analysis

In this study, the central assumptions were tested to ensure the accuracy of the statistical measures and the correct interpretation of the results. Shapiro-Wilk statistic results were used to test the normal distribution of the data, and for testing the homogeneity of variances, Leven's test was calculated for the assumptions that the variances of the two groups are equal. It was found that the premises have not been violated. Moreover, sample sizes were calculated using an a priori power analysis performed on the data from this study that compared EGs to CGs using G*Power version 3.1.9.7. Using the criteria proposed by Cohen (1988), the effect size was 1.34, which is substantial. The minimum sample size with this effect size is $N = 10$ for a significance level of .05 and power of .80. Therefore, the obtained sample size of $N = 45$ is more than sufficient for the purpose of the present study.

To answer research question one, three kinds of analysis were used. Firstly, mean scores and standard deviations were used to compare the differences between the scores of the EGs and CGs before and after the treatment. Secondly, the independent sample t-test was used to determine the initial comparison of the two groups before the intervention. Hake's normalized gain was calculated to evaluate the intervention's impact. To answer research question two, descriptive statistics of mean scores and standard deviation were used to compare NSLMAT scores differences for both the EGs and the CGs. Mean gain scores and standard deviations were also used to calculate Cohen's d effect sizes. One-way Analysis of Variance (ANOVA) was employed to assess whether there were any statistically significant differences (p) between the two groups before the educational intervention. It was found that pre-test scores at $p < .05$ were not significantly different between the experimental and control groups. A paired t-test was done to determine any statistically significant difference between the two groups pre-and post-test scores in NSLMAT.

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Research Results

Impact of CSs on Students' Performance in NSLOM

NSLMAT mean scores (*M*) and standard deviations (*SD*) for the participant were calculated using SPSS 26. The independent sample t-test revealed that the two groups' pre-test scores at the $p < .05$ level were not statistically different. For the EG ($M = 18.00$, $SD = 3.24$) and the CG ($M = 17.51$, $SD = 2.84$) conditions; $t\,(88) = .093$, $p = .927$. This means that students in the two groups are comparable, as illustrated in Table 5.

Table 5

An Independent-Samples t-test of NSLMAT of the Two Groups

Groups	*N*	*M*	*SD*	*t*	*df*	*p*
Pre- CG	45	17.51	2.84			
Pre- EG	45	18.00	3.24	0.093	88	.927

Table 6 displays the outcomes of the students' performance scores before and following the intervention (simulations) for each group independently. According to the mean differences, the EGs appeared to have fared better on all test questions before receiving any treatment; on the pre-test and the post-test, the EG outperformed the CG by 0.48 and 5.20 points, respectively.

Table 6

Performance Results of NSLMAT Stratified by Group

	EG *(N = 45)*			CG *(N = 45)*		
	M	*SD*	*SEM*	*M*	*SD*	*SEM*
Pre-test	18.00	3.24	.48	17.51	2.84	.42
Post-test	25.51	3.62	.54	20.31	4.09	.61

The following formula was used to calculate the normalized gain factor.

$$g = \frac{Post\ test\ \% - Pre\ test\%}{100\% - Pre\ test}$$

Hake (1998) categorized the average gain values as; high gain scores if ($g \geq 0.7$) medium gain scores if ($0.3 \leq g < 0.7$), and low gain if ($g < 0.3$). As seen in Table 7, the results showed that EGs, which used the CSs to learn the concepts with NSLOM, had medium gain scores, while the CGs who treated the same topic face-to-face as an educational strategy had scored low gain score ranges.

Table 7

Mean Gain of the Two Groups

Groups	N	M Pre-test (%)	M Post-test (%)	Mean difference (%)	Gain (g)
CG	45	56	63	7	.16
EG	45	56	80	24	.55

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Differences in Performance in NSLOM

Table 8 shows that the students in the CG (*M* =17.51, *SD* = 2.84) and in the EG (*M* = 18.00, *SD* = 3.24) have the same performance in the pre-test. There was a higher mean in the post-test of the CG and EG, with (*M* = 20.31, *SD* = 4.09) and (*M* = 25.51, *SD* = 3.62), respectively.

Using descriptive statistics, the intervention's effect on the EG's NSLOM performance was determined by comparing their pre-and post-test scores on the NSLMAT. The EG has a higher mean score (*M* = 25.51, *SD* = 3.62) than the CG (*M* = 20.31, *SD* = 4.09). Cohen (1992) described the degree of these effects, where *d* = 0.20 is small effect size, *d* = 0.50 is medium effect size, and *d* = 0.80 is large effect size.

Table 8
Performance in NSLOM Gains Stratified by Group

	Pre-test			Post-test			
Group	***M***	***SD***	***Variance***	***M***	***SD***	***Variance***	**Cohen's d***
EG	18.00	3.24	10.500	25.51	3.62	13.119	2.56
CG	17.51	2.84	8.074	20.31	4.09	16.765	0.73

*: d = effect size

Overall, CSs-based education had the most significant effect on raising students' understanding of NSLOM topics compared to face-to-face teaching.

As illustrated in Table 9, a one-way ANOVA found that the post-test scores at *p* < .05 for the two groups were significantly different [*F* (1,89) = 40.718, *p* < .05].

Table 9
One-Way ANOVA of the Post-test Scores

	SS	***df***	***SS***	***F***	***p***
Between Groups	608.40	1	608.40	40.718	< .05
Within Groups	1314.88	88	14.94		
Total	1923.28	89			

The results of a paired-sample t-test, which was performed to determine whether there was a statistically significant difference between the mean pre-test and post-test scores for the EG, are presented in Table 10. It showed statistically significant differences between the pre-test and post-test scores in the EG, which can be reported as *t* (44) = 11.133, *p* < .05.

Table 10
Paired-Sample t-test of Pre and Post-test of EG

Pre-test		Post-test				
M	***SD***	***M***	***SD***	***t***	***df***	***p***
18.0000	3.24037	25.51	3.62	11.133	44	p < .05

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Gender Differences in Performance in NSLOM

Table 11 demonstrates that there were no statistically significant differences in the performance of male students in either the CGs (*M* = 17.76, *SD* = 3.03) or the EGs (*M* = 18.04, *SD* = 3.43); they had similar performance as in the pre-test. This was similarly the case for the female students in the CG (*M* = 17.20, *SD* = 2.62) and in the EG (*M* = 17.95, *SD* = 3.06). The EGs had a higher mean score than the other groups.

The independent *t*-test for the equality of means indicated that the difference in the means was not a significant *t*-test (*t* (88) = 0.502 and *p* = .617), which suggests that there was no difference between the two groups of male and female students before the teaching started in the section of NSLOM (Table 12).

Table 11

Descriptive Statistics for the Pre-Test Based on Gender

Gender	Condition	*N*	*M*	*SD*
CGs	Male	25	17.76	3.0315
	Female	20	17.20	2.6278
EGs	Male	25	18.04	3.4337
	Female	20	17.95	3.0689

Table 12

An Independent-Samples t-test of NSLMAT of the Two Gender

	Groups	*N*	*M*	*SD*	*t*	*df*	*p*
Pre-test	Male	50	17.90	3.20			
	Female	40	17.57	2.84	0.502	88	.617

There was a statistically significant difference between the mean scores of the male students in the EG on the pre-test *(M* = 17.90, *SD* = 3.20) and the post-test (*M* = 22.42, *SD* = 4.68), as shown in Table 13. Both the pre-test results (*M* = 17.57, *SD* = 2.84) and the post-test results (*M* = 23.52, *SD* = 4.59) for the female students were found to be significantly different from one another. The findings presented above indicate that CSs significantly impacted female students (*d* = 1.49) and male students (*d* = 2.44). These findings show that CSs assisted female and male students in better comprehending NSLOM topics.

Table 13

Performance in NSLOM Gains Stratified by Gender

	Pre-test		Post-test			
Gender	*M*	*SD*	*M*	*SD*	Mean Difference	*d**
Male	17.90	3.21	22.42	4.68	4.52	1.13
Female	17.57	2.85	23.53	4.59	5.95	1.56

*: d = Cohen's effect size

Discussion

Results of research question one showed that students in the EG performed better than students in the CG, confirming that CSs, through visualization, helped to establish connections and draw attention to the concepts and details of NSLOM. Due to this, students become active participants as they attempt to mimic the reality of the

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small world and include many examples and genuine relationships (Hirshman & Bjork, 1988; Stieff et al., 2005) in ways that aid understanding of NSLOM. Furthermore, Husain (2010) argued that CSs encourage independence, experiential, and discovery learning among learners and cognitive engagement, which might have contributed to this better performance in NSLOM.

The findings of this study aligned with the theoretical framework that encourages the active construction of knowledge. In the constructivist view, students learn by their potential and cognitive capacity, constructing knowledge through collaboration and personal engagement with learning activities. According to Philips (1997), constructivism allows students to participate in the learning process and develop their knowledge actively. In the EG, students were provided and guided with more CSs embedded tasks, allowing them to use more reflective learning strategies in different lessons. Hence, CSs learning environment will enable students to learn by constructing knowledge through active engagement and participation. The findings of this study were consistent with those of earlier studies on CSs effect based on a constructivist approach to alleviating confusion in physics learning/teaching, including those reported by Ghadiri et al. (2016) and Vick (2010). As CSs make visual modeling more realistic and abstract systems become more concrete (Wibowo et al., 2016), it is well suited for reducing the complexity of learning through tools such as slow-motion experimental observations, hypothesis formation, experimentation, and data interpretation (Chang et al., 2008; Posner et al., 1982), as well as clarifying observations (Coştu et al., 2017; Renken & Nunez, 2013). The results of this study were also similar to the study of Sarı et al. (2017), in which their research showed that the 5E teaching model integrated into the CSs has the potential to help 11th-grade students to improve their physics academic performance.

The results of research question two showed that students in the EG performed better than students in the CG. That is, students were doing better using CSs. A possible explanation for these results is that students may be motivated to understand the concepts better, which may have enabled the students to achieve better grades. CSs can produce more positive results than those taught in face-to-face education, which may make students more interested in extending their learning. Through these CSs related activities, students could gain a deeper understanding of the basic principles of each lesson (Mengistu & Kahsay, 2015; Podolefsky et al., 2010; Quellmalz et al., 2012). These results encourage us to use CSs as an alternative educational tool to overcome difficulties encountered by students when learning physics.

Another possibility is that the EG showed significantly better performance than CG due to increased student participation. CSs provided tools that make physics education more effective. Efficiency is reflected in two aspects. First, learning by CSs can save students' time in complex calculations and manipulations (Widiyatmoko, 2018; Wilson, 2016). Second, CSs may enable students to be more organized and store and process data (Stern et al., 2017). This gives students more opportunities to communicate and interact with each other. For example, students can talk to each other and discuss possible solutions and methods. They can advance various assumptions, test these assumptions, and see the results of these tests instantly. In this way, CSs can allow students with opportunities to discuss and interact with each other and with content. Such interaction may lead to a better understanding of physics.

The results of this study were in line with previous research on the effects of CSs, including those reported by Bayrak (2008), Holec et al. (2004), Mengistu and Kahsay (2015), Çetin (2018), Sreelekha (2018), and Sarı et al. (2017). Furthermore, the results of this study also supported the results of two meta-analysis studies. In the first meta-analysis, 29 experimental studies concluded that CSs education was more effective than traditional classroom education on students' achievement (Liao & Chen, 2007). In another meta-analysis, Rutten et al. (2012), who reviewed 510 experimental studies involving CSs, concluded that CSs improved learning outcomes and facilitated students' conceptual understanding. CSs can also enhance students' satisfaction, participation, initiative, and perception of the classroom environment.

With regard to research question three, Cohen's effect size suggests that male and female students benefited more from CSs in the NSLOM. This is because CSs provide learners with a realistic experience through which knowledge can be acquired and manipulated to understand better the relationship between the concepts studied. The results of this study also suggest that female students increased their understanding more than male students who used CSs. While female students initially lagged far behind their male counterparts in performance, using CSs helped them to improve and narrow the gap. These improvements may be related to students' confidence (OECD, 2015). When students are more confident, they have greater leeway to make mistakes and engage in the process of learning via trial-and-error fundamental to acquiring science/physics knowledge. Moreover, Next Generation Science Standards (2013) claimed that engaging in scientific practice helps students understand the development of scientific knowledge. This direct participation gives them an understanding of the many methods used

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to explore, model, and interpret the world.

Conclusions and Implications

The results of this study suggest that the application of CSs in classroom teaching offers secondary school students other opportunities to improve their performance in physics. In this context, the results have been summarized as follows. First, this study found that CSs improved students' understanding of NSLOM. CSs classes included various activities to help students acquire and integrate physical concepts. Second, the result of this study challenges claims that gender differences are closely related to the science curriculum, favoring boys. In this study, female students performed as well as their male counterparts. Therefore, it will be safe to say that gender differences are on their way to decline in the UAE context, considering these findings and other findings such as those reported by trends in International Mathematics and Science Study (TIMSS) 2019. Finally, the results support the constructivist view that knowledge is constructed gradually by students and not directly transmitted by teachers. Students can manipulate parameters and use the effects of these manipulations in constructive methods to build new meanings. Therefore, constructivist strategies should be given more attention, as they provide students with opportunities to design, test, and evaluate their learning and a profound grasp of physical phenomena.

Furthermore, the CSs as a teaching approach should be integrated systematically into teaching physics to improve their physics performance. As such, decision-makers and schools should gradually move toward CSs integration to enhance students' understanding. Finally, this study shows how CSs can be helpful for teachers. Physics teachers now have a tool to help students learn in the classroom and enhance students' confidence in the classroom, boost their attitudes toward physics, make physics more enjoyable for students, and enrich students' knowledge, which can be helpful for upper-level physics classes. Often teachers are challenged by unmotivated students in classrooms who are demotivated by their dislike of physics and potentially poor skills. CSs may provide teachers with the opportunity to provide students with a tool that allows them to enjoy physics and improves their physics skills. Nevertheless, interactive CSs do not replace the role of teachers or traditional experimental laboratories. Teachers should use CSs as a helpful reserve tool to further improve student learning outcomes.

Future Research Opportunities

Given several studies supporting the positive effects of CSs on learning, how CSs could influence the development of these much-needed skills in schools should be the focus of future research. Although the findings reported in this study may need to be treated with the appropriate caution, future research studies may replicate this study to explore other variables such as student and teacher attitudes toward CSs, student background, and home variables. Future research is also needed to provide a holistic view of the NSLOM topic by expanding the sample to include other classes and other stages of education, including primary and higher education stages in private and public schools.

Declaration of Interest

The authors declare no competing interest.

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Appendix A

1. An object of mass 10 kg is accelerated <u>downward</u> at (2m/s^2). If (g = 10 m/s^2), what is the force of air resistance?

A 20 N upward

B 80 N upward

C 120 N upward

D 200 N upward

---

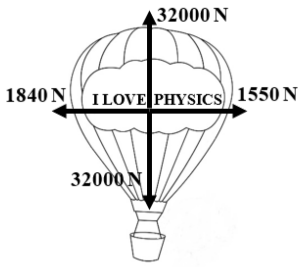
2. The free-body diagram shows the forces on a balloon. In which direction will the balloon accelerate?
(Note: the length of the arrows doesn't represent the amount of the force).

A Up ↑

B Down ↓

C Right →

D Left ←



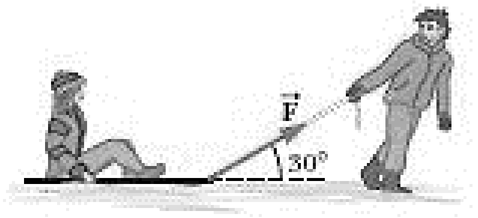
3. A boy pulls his sister by applying a force equal to 50 N at an angle of 30 ° north of east.
Which two components are equivalent to the applied force?

A 43 N- east and 7 N- north

B 43 N- east and 25 N- north

C 35 N- east and 15 N- north

D 25 N- east and 25 N- north



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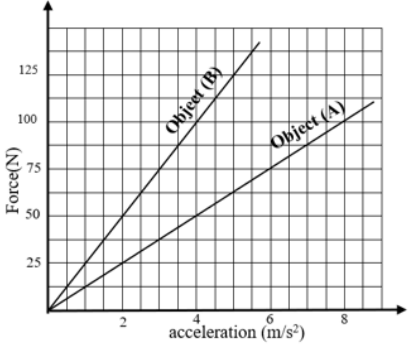
4. The figure on the right represents the relationship between the force acting and acceleration of two objects, $\boldsymbol{A}$, and $\boldsymbol{B}$. Which of the following statements is true?

A Object A has a mass greater than object B.

B Object A has a mass equal to object B.

C Object B has a mass greater than object A.

D The mass of the two objects cannot be compared.



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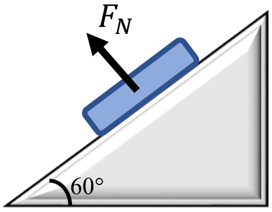
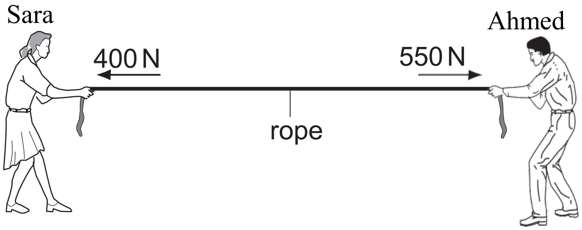
5. A book with a mass of 6.0 kg is held in equilibrium on a surface inclined at an angle of 60 °. What is the normal force $\mathbf{F_N}$ exerted on the book?



- **A** 30 N
- **B** 52 N
- **C** 60 N
- **D** 104 N

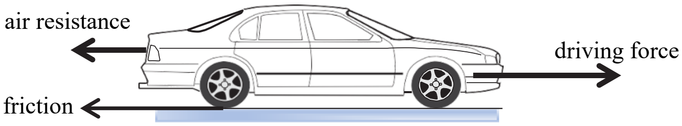
6. Ahmed and Sara are pulling a light rope in opposite directions. The forces acting on the rope are shown in the diagram. Which single force has the same effect as the two forces?



- **A** 150 N acting towards the girl
- **B** 550 N acting towards the boy
- **C** 150 N acting towards the boy
- **D** 400 N acting towards the girl

---

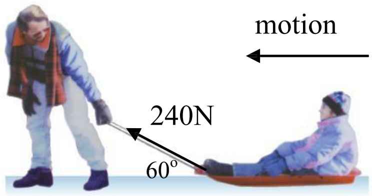
7. Which combination of forces would result in the car moving at constant speed?



	air resistance	friction	driving force
A	500 N	800 N	1300 N
B	500 N	1300 N	800 N
C	800 N	1300 N	500 N
D	1300 N	800 N	500 N

---

8. Ahmed pulls his brother 80 kg with a force of 240 N at an angle of 60° on a frictionless horizontal surface, as shown. What is the acceleration of his brother?



- **A** 4 m/s^2
- **B** 3 m/s^2
- **C** 2.6 m/s^2
- **D** 1.5 m/s^2

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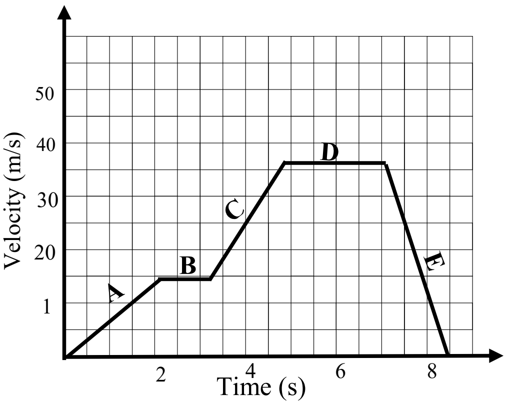
9. The graph shows Saeed's car journey from his house to school library. During which section(s) does the acceleration equal zero?



A A & C & E

B B & D

C A & C

D E

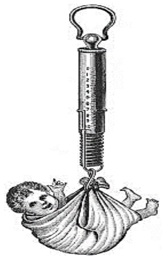
10. Consider the baby being weighed in the shown figure. What is the mass of the baby if a scale reading is $67\ N$. Consider the acceleration due to gravity to be $g = 10\ m/s^2$.

A 10 kg

B 670 kg

C 6.7 kg

D 0.0 kg



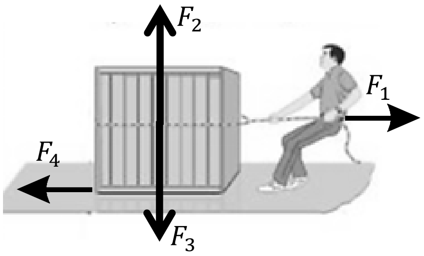
11. The figure shows a free-body diagram, a man exerting force on a box to slide it across the floor. If the box is sliding at a constant velocity, which of the following forces in the free-body the diagram must be equal in magnitude?

A F_1 & F_4

B F_1 & F_3

C F_4 & F_2

D F_4 & F_3



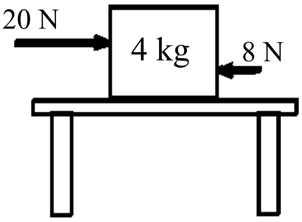
12. The figure shows that two forces, F1= 20 N and F2= 8 N, are acting on a 4 kg object. What are the magnitude and the direction of the acceleration?

A 4 m/s^2 to the left (the same direction of F_2)

B 2 m/s^2 to the left (the same direction of F_2)

C 4 m/s^2 to the right (the same direction of F_1)

D 3as/s^2 to the right (the same direction of F_1)



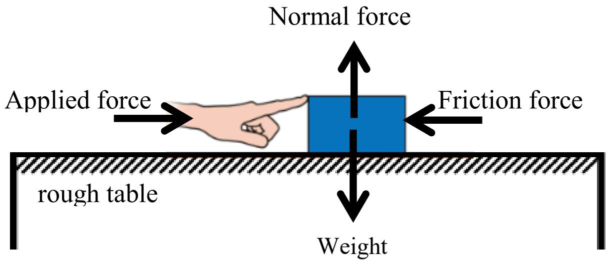
13. According to the diagram, if the mass of the box increased, which force could remain constant?

A Applied force

B Normal force

C Friction force

D Weight



14. A cord and frictionless pulley supports a bag with a weight of 30 N . A force of 15 N acts on the bag and, one end of the cord is pulled by a force of 100 N, as shown in the figure.

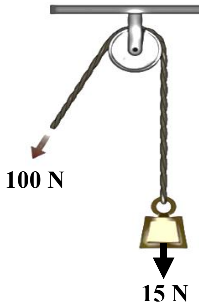
Determine the net force acts on the bag?

A 115 N

B 85 N

C 70 N

D 55 N



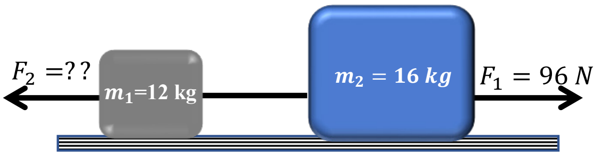
15. The diagram shows two crates, $m_1 = 12\ kg$ and $= 16\ kg$, respectively, are connected with light inextensible string rope. A force to the right of $F_1 = 96\ N,$ is applied. The crates move with an acceleration of 2 m/s^2 to the right. What the magnitude of force F_2?

A $F_2 = 72\ N$

B $F_2 = 56\ N$

C $F_2 = 40\ N$

D $F_2 = 48\ N$



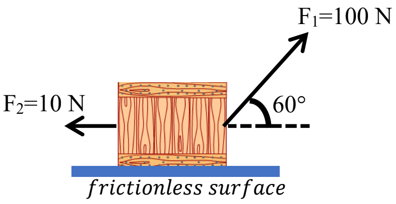
16. Two forces are acting on an object with a mass of 20 kg, as shown in the figure below. What will be the acceleration of the object?

A 0.5 m/s^2

B 2 m/s^2

C 4.5 m/s^2

D 5 m/s^2



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