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The effect of computer simulations on students' conceptual and procedural understanding of Newton's second law of motion

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Abstract
This study aims to assess the impact of computer simulations (CSs) within an inquiry-based learning (IBL) environment on grade 11 students' performance in Newton's second law of motion (NSLOM). The study sample consisted of 90 male and female students selected from a population of two public schools in Al Ain city in United Arab Emirates (UAE). The study employed a pre- and post-test quasi-experimental design involving four equally distributed grade 11 physics classes: two as experimental groups (EGs) (including 45 CS-bound students studying under scientific inquiry instructions) and the other two as control groups (including 45 CSs-free students studying under traditional face-to-face instructions). Newton's second law of motion achievement test (NSLMAT) was used to evaluate students' performance in NSLOM. Descriptive analysis was conducted using effect sizes and a paired-sample t-test. Overall, results suggested that, compared to face-to-face instruction, CSs were more successful in promoting students' understanding of NSLOM topics. Moreover, EGs showed noticeable conceptual and procedural performance gains. The results indicated that CSs within an IBL environment helped female (d=2.10) and male (d=2.94) students better understand NSLOM conceptual topics. CSs within an IBL environment also helped male (d=0.88) and female (d=0.72) students better understand NSLOM. Finally, if properly designed, CSs within an IBL environment can significantly improve student learning of NSLOM. Therefore, the study recommends creating a supportive learning environment to encourage the use of CSs for purposes other than information presentation. Incorporating simulations into practical activities, problem-solving exercises, or group discussions could improve students' critical thinking and problem-solving abilities. Allowing students to practice using the simulation before implementing it in actual learning activities is also crucial.

Keywords: computer simulations, NSLOM, inquiry-based learning, conceptual understanding, procedural understanding, UAE

INTRODUCTION

In classical mechanics, Newton's second law of motion (NSLOM) is the most important and central topic (Itza-Ortiz et al., 2003; Mico et al., 2010). Sari and Madlazim (2015) stated that understanding NSLOM is essential for understanding mechanics. NGSS (2013) described NSLOM as the movement of an object depends on the sum of the forces acting on it. The equation for this law is {F=m.a} (Net force=[mass][acceleration]) (Coelho, 2018; Mico et al., 2010; Serway & Jewett, 2014). Despite how crucial it is to teach students about the relationship between force and motion, many textbooks present the NSLOM in such an

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Contribution to the literature

- The study provided an example of inquiry learning integrated with a technology environment and interactive simulation.
- The use of computer simulations in learning will enhance the teaching process, especially in the field of science.
- Students' understanding of science topics (physics, chemistry, biology, and geology) will increase as they learn through computer simulations.

abstract way that many students need help to grasp its significance (Mico et al., 2010). Visualization tools, such as computer simulations (CSs), if used in instruction, are likely to facilitate students' understanding and enable them to create or draw their representations (Abdulrahaman et al., 2020; Ariano et al., 2023; Coelho, 2018).

Seoane et al. (2022) defined CSs as a demonstration of the dynamic behavior of a system according to an approximate mathematical model that is transformed into discrete algorithms to be implemented on a computer. According to Candido et al. (2022) and Zacharia and Anderson (2003), using CSs as part of an instructional technique to teach physics' abstract concepts can provide students with the academic tools they need to comprehend these concepts more thoroughly. Other researchers claimed that CSs could allow students to learn physics concepts and apply them in a virtual environment with manual skills that can only be obtained in real-world labs (Al Mansoori et al., 2022; Bozkurt & Ilik, 2010; Quellmalz et al., 2012; Rutten et al., 2012). Students should actively participate in data collection and analysis with the aid of CSs to ensure that they can identify any existing thinking gaps they could have (Philips, 1997; Srisawasdi & Panjaburee, 2015).

On the other hand, the tradition of inquiry-based learning (IBL), which has proven to be an effective instructional strategy, is often seen as an educational approach involving students in experiments and investigations to construct their knowledge (Abdallah, 2018; Avsec & Kocijancic, 2014; Gerhátová et al., 2021). Within the context of IBL, Peffer et al. (2015) found that using CSs in the classroom provides students with a new opportunity to learn science through hands-on application, allowing them to undertake unique investigative activities in the classroom. In addition, it offers science teachers and students a flexible environment to perform scientifically realistic inquiries.

Problem Statement

United Arab Emirates (UAE) certificate of high education attests to the fact that students' performance in physics in national examinations remains subpar despite the government's significant expenditure on teaching and learning reforms implemented by the government (MOEY, 2000). Moreover, the results of international comparative examinations in science over the years have been dismal, as shown by trends in international mathematics and science study (TIMSS) and program for international student assessment (PISA) (Martin et al., 2015; OECD, 2015b). A significant area of deficiency for both grade levels was in one cognitive domain, "applying." (Martin et al., 2015; OECD, 2015b). Moreover, Ministry of Education (MOE) Department of Assessment analysis showed a persisting need to improve the conceptual understanding of UAE students in science education (Alam, 2020; Kamal & Trines, 2018).

According to D'Angelo et al. (2014), Mirana (2016), and Smetana and Bell (2012) using CSs as IBL settings can enhance students' theoretical understanding and develop investigative process skills and learning confidence. Therefore, this study fills the gap in the need for more research on the efficacy of CSs in teaching physics, specifically NSLOM, within the context of scientific inquiry instruction at the secondary school level.

Purpose of the Study

This study investigated how CSs affect grade 11 students' conceptual and procedural knowledge of NSLOM compared to face-to-face instruction within an IBL environment.

Questions of the Study

To achieve this purpose, the following research questions were addressed:

1. Is any statistically significant difference in student performance regarding the conceptual and procedural understanding of NSLOM between grade 11 students who studied through CSs within the scientific inquiry and students who learned through traditional face-to-face instruction?
2. Is any significant statistical difference in performance regarding procedural understanding in NSLOM between grade 11 students who studied through CSs within the scientific inquiry and students who learned through traditional face-to-face instruction?
3. Are there gender differences in conceptual vs. procedural understanding in NSLOM between grade 11 students who studied through CSs

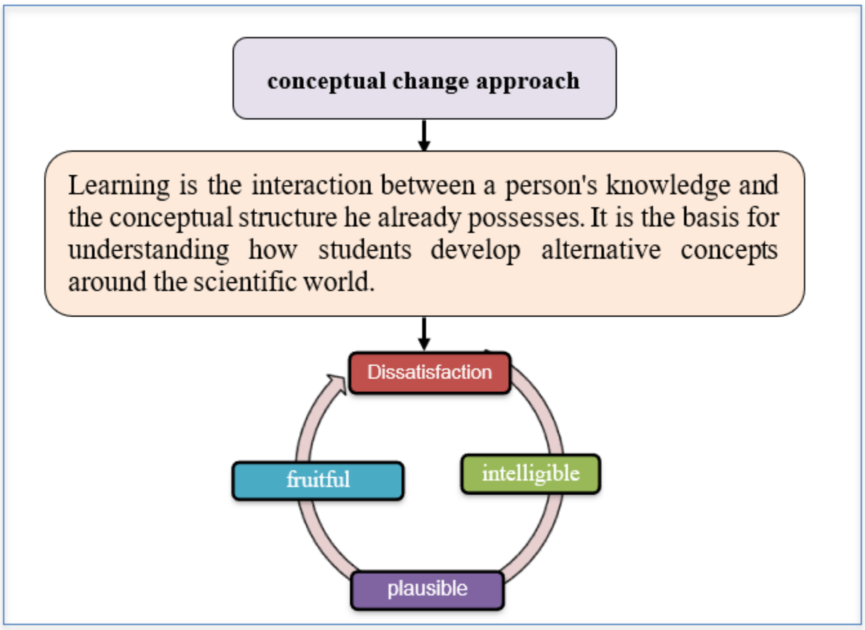

Figure 1. Theoretical framework of this study (Source: Authors' own elaboration)

within the scientific inquiry and students who learned through traditional face-to-face instruction?

Significance of the Research

This study aimed to explore practices and strategies that enhance the teaching of physics in UAE and assist teachers in comparing these strategies with international standards. Moreover, it may enable students to participate effectively in meaningful teaching and learning processes. In addition, numerous limitations make it often difficult for teachers to apply inquiry learning in physics classrooms. Therefore, this study provided a demonstrable example of how inquiry learning is implemented and integrated with a technology environment and interactive simulations in the context of UAE. To the best of our knowledge, in UAE, research is scarce on how CSs affect students' learning. In addition, limited research looked at students' difficulties in learning NSLOM at a high school level. Finally, the findings of this study could propose a new pathway for teaching the NSLOM in the high schools of UAE, where physics education is a key to science learning.

LITERATURE REVIEW

Theoretical Framework

Theoretical framework of this study is based on a conceptual change approach (**Figure 1**).

Hennessey (1993) mentioned that the process of learning within the perspectives of the conceptual change approach depends on the extent to which the individual's conceptions are integrated with new information. If learners are dissatisfied with previous concepts and the available alternatives conception are intelligible, plausible, and fruitful, accommodation of the new conception may follow (Dole & Sinatra, 1998; Posner et al., 1982).

In the context of CSs, students will revise, clear up ambiguities, and propose conceptual modifications; students actively create an understanding of science. CSs would bridge prior knowledge and information acquired in an IBL environment (Samsudin et al., 2016; Tsai et al., 2022). CSs also enhance the delivery of the teaching material by making visual modeling more realistic, abstract systems more tangible, and allowing the implementation of graphical representations of abstract systems (Wibowo et al., 2016).

Conceptual and Procedural Understanding

Conceptual knowledge is students' ability to comprehend and solve physics problems that do not involve computation or calculations. These problems generally involve written descriptions or equations involving only variables (Nieswandt, 2007). According to the research, using CSs is an effective method for improving conceptual understanding of physics subjects. For example, Faour and Ayoubi (2018) studied the impact of CSs on the conceptual knowledge of 10th graders regarding the DC circuit and discovered that CSs greatly improved DC circuit concepts. Mirana (2016) investigated the effects on students' conceptual knowledge of electricity of a created lesson integrating CSs and a constructivist approach. The research was carried out utilizing physics education technology (PhET) and other web-based simulations. The findings demonstrated that CSs might effectively increase students' physics understanding. Hazelton et al. (2013) wanted to see how real-world circuits, or an interactive circuit simulation affected undergraduate students' learning. According to the results, students who used simulations completed this tutorial faster and scored higher on conceptual questions than students who used actual circuits.

Procedural knowledge is the way of doing something. It encompasses the methods of inquiry as well as criteria for using skills, algorithms, techniques, and methods, including knowledge of subject-specific skills and algorithms, knowledge of subject-specific techniques and methods, and knowledge of criteria for determining when to use appropriate procedures (Anderson et al., 2001). The study proved the significance of CSs in the procedural comprehension of physics concepts. Aoude (2015), for example, investigated the impact of CSs on students' physics concepts linked to uniform circular motion in UAE. The study found that the experimental group (EG) (who used CSs to teach) had a statistically significant advantage over the control group (CG) (who used video to teach), particularly in terms of procedural knowledge. Adam et al., (2020), Jimoyiannis and Komis (2001), and Nestel et al., (2011) have proposed that CSs can help students overcome cognitive limitations.

Impact of Computer Simulations on Students' Learning

CSs are programs that represent real systems or phenomena and have many functions that are particularly useful in science education (Blake & Scanlon, 2007; de Jong & van Joolingen, 1998). CSs are designed to facilitate teaching and learning through visualization and interaction with dynamic models of natural phenomena. Holec et al. (2004) argued that CSs might communicate dynamic information more accurately and help students to visualize various phenomena. They could enable students to visualize things that are usually too fast, too slow, or hidden (Holec et al., 2004, p. 230; Widiyatmoko, 2018). CSs may provide students with a realistic experience through which knowledge can be constructed and manipulated to understand better the relationship between the concepts studied (NGSS, 2013; Widiyatmoko, 2018). In addition, CSs may allow students to visualize objects and processes that are usually beyond the students' control in the natural world (de Jong et al., 2013). Consequently, CSs can be beneficial by repeating multiple experiments (Widiyatmoko, 2018).

Previous research studies showed that using CSs is a practical approach to enhancing conceptual understanding of physics concepts. For example, Faour and Ayoubi (2018) looked into how the use of CSs affected students in the 10th grade's conceptual comprehension of DC circuits. Data analysis revealed that the student's understanding of concepts of DC circuits was significantly improved. Additionally, Bayrak (2008) investigated how CSs affected how well undergraduate students learned geometric optics. Bayrak's (2008) findings demonstrated a beneficial association between student accomplishment and CSs' enhancement of physical comprehension.

Computer Simulations and Inquiry-Based Learning

Findings from previous research studies noted that students' understanding of fundamental physics concepts could be improved only through the active participation of students in learning activities (Adams et al., 2008; Hannel & Cuevas, 2018; Lamina, 2019; Posner et al., 1982). Therefore, physics teachers need to teach physics through exploration, discovery, demonstration, simulations, practical work, laboratory-based experience, and other practical experiences (Stern & Huber, cited in Batuyong & Antonio, 2018; Lamina, 2019).

Within the context of IBL, Peffer et al. (2015) and Shudayfat and Alsalhi (2023) found that the use of CSs in the classroom provided students with new opportunities to learn science in practice, permitting them to undertake investigative activities that are typically not doable in the classroom, along with equipping teachers and students' greater flexibility to perform scientifically realistic inquiries. Banda and Nzabahimana (2021) found that using PhET simulations effectively improves students' physics conceptual understanding. This result was extracted from reviewing 31 studies conducted in many different countries and education systems about using PhET simulations to teach various physics topics; moreover, PhET simulations can be integrated into many active learning instructional environments, including inquiry-based activities.

The 5Es model strongly emphasizes students' discovery and a greater comprehension of indirect instruction (Duran & Duran, 2004). This model proved effective in students' mastery of topics, scientific reasoning, interest, and attitude (Lo, 2017, p. 39). 5E consists of five stages (**Table 1**). These are engage, explore, explain, elaborate, and evaluate.

Given the strong evidence from previous research findings, CSs are powerful tools that enhance student understanding when implemented in inquiry-oriented instruction for their ability to cognitively engage learners in higher-order thinking levels and thereby facilitate conceptual and procedural understanding.

METHODOLOGY

Population and Sampling

This study targeted grade 11 (16-17 years old) students from two secondary schools in one of UAE cities chosen as a purposeful convenience sampling; one for boys taught by male science teachers and one for girls

Table 1. Summary of the 5E instructional model (adapted from Lo, 2017)

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

Table 2. groups

Groups	Gender	Number (n)	Total
CG	Female	20	45
	Male	25	
EG	Female	20	45
	Male	25	

Table 3. Experiment design pattern

Groups	Pre-test	Treatment	Post-test
CG	Applied	**No treatment**	Applied
EG	Applied	Receiving treatment	Applied

led by female science teachers. Additionally, the two groups were enrolled in the advanced stream for the 2019-2020 academic year. The sample of this study consisted of 90 students, and all of them were selected from the advanced stream. There was three grade 11 classes in the girl's school; one of them was randomly to receive face-to-face instruction (CG), while CSs environment (EG) was given to the second class selected randomly. There was four grade 11 classes at the boys' school; one class was chosen randomly to be a CG and another one to be an EG. The characteristics of the participants are outlined in **Table 2**.

Research Design

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 CG. The study employed a quasi-experimental pre-/post-test design/CG design, as shown in **Table 3**. This design was the most appropriate one as it provided an environment for comparing the two groups based on the intervention.

Materials

Newton's second law of motion lab simulation

To enhance the theoretical understanding of how objects move and how they accelerate, interactive simulations of the forces and computational motions obtained from PhET were used as inquiry tools for students (Adams et al., 2008). The Java-based NSLOM simulation used in the current study could be downloaded and installed on students' PCs via the free-to-use website http://phet.colorado.edu. Students were asked to explore the many features of the NSLOM simulations after receiving detailed instructions on how to use them. A series of controls in the control bar area allowed students to change analog input parameters. Each student then used the pre-explanation given in the NSLOM worksheet to conduct experiments. The simulations of NSLOM are different simulations related to NSLOM. **Figure 2** shows screenshots of one of the simulations. PhET allowed students to interact with Newtonian representations of force and motion and enabled them to create their experiments.

Research Instruments

Newton's second law of motion achievement test

The study employed multiple-choice questions on NSLMAT to evaluate students' performance on NSLOM. NSLMAT, created to test a student's comprehension of conceptual and procedural data, was also used to assess impact of experimental treatment.

NSLMAT validation

The content validity of NSLMAT was established via the expert opinions of several science educators. The initial constructed multiple-choice questions were given to a group of science educators, including ten high school physics teachers, inspectors, and professors. The experts were tasked to evaluate whether the test would meet the objectives for which it was developed. In addition, they were asked to ensure that language was structurally appropriate and scientifically accurate and that the applicability of the measurement tool was convenient. The experts were also asked to assess the clarity and suitability of the study for participants. In light of the feedback received, the researchers modified the initial form by rewriting some phrases and excluding some. Besides, the symbols were rewritten in ways that were similar to one presented in the book published in UAE for advanced 11th graders in 2019. After all the changes were made, the final version of the test consisted of 16 questions. The focus of the test items was on:

(1) conceptual understanding and

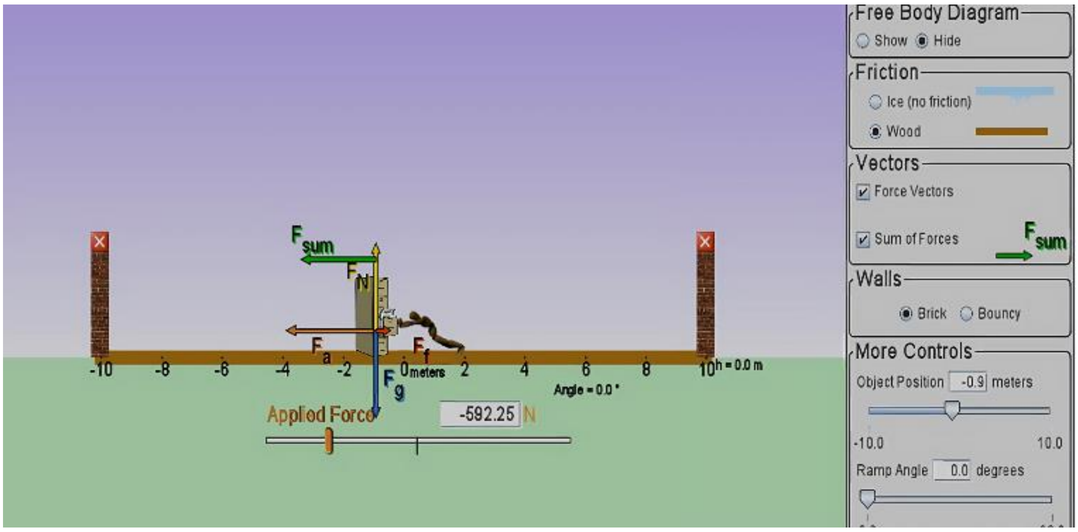

Figure 2. Screenshot of CSs with a visual representation of forces (Source: https://phet.colorado.edu/sims/cheerpj/motion-series/latest/motion-series.html?simulation=ramp-forces-and-motion)

Table 4. Distribution of items in final version of NSLMAT

Knowledge domains	Items
Procedural knowledge	Q2, Q4, Q6, Q7, Q9, Q10, Q11, & Q13
Conceptual knowledge	Q1, Q3, Q5, Q8, Q12, Q14, Q15, & Q16

Table 5. Reliability statistics for NSLMAT exam

Cronbach's alpha	Part 1	Value	0.741
		Number of items	16[a]
	Part 2	Value	0.844
		Number of items	16[b]
		Total number of items	32
Correlation between forms			0.611
Spearman-Brown coefficient		Equal length	0.759
		Unequal length	0.759
Guttman split-half coefficient			0.758

Table 6. Scale statistics of NALMAT

	M	Variance	SD	Number of items
Part 1	13.73	3.857	1.964	15[a]
Part 2	12.03	4.309	2.076	13[b]
Both parts	25.77	13.151	3.626	28

(2) procedural understanding.

Table 4 shows the distributions of items in both conceptual and procedural domains.

NSLMAT reliability

By contrasting the findings from the odd numbers with the results from the even numbers, as shown in **Table 5** and **Table 6**, respectively, split-half dependability was determined to evaluate the internal consistency of this NSLMAT.

Because the two parts' reliability and variance were not equal, the researchers adopted Guttman split-half reliability coefficient, which was found to be 0.758. This meant that scores were acceptable in terms of reliability.

Table 7. Correlation coefficients between each domain with overall score of test

Knowledge domain	Coefficient of correlation with total score	Significance level
Conceptual	0.759**	0.01
Procedural	0.952**	0.01

Note. **Correlation is significant at 0.01 level (2-tailed)

Table 8. Correlation coefficients between questions & overall score of conceptual domain

Question no	Correlation coefficient	Significance level
2	0.829**	0.01
4	0.103	Not significant
6	0.793**	0.01
7	0.829**	0.01
9	0.712**	0.01
10	0.671**	0.01
11	0.955**	0.01
13	0.612**	0.01

Note. **Correlation is significant at 0.01 level (2-tailed)

Table 9. Correlation coefficients between questions & overall score of procedural

Question no	Correlation coefficient	Significance level
1	0.840**	0.01
3	0.694**	0.01
5	0.885**	0.01
8	0.961**	0.01
12	0.252	Not significant
14	0.813**	0.01
15	0.759**	0.01
16	0.955**	0.01

Note. **Correlation is significant at 0.01 level (2-tailed)

The internal validity of the test for conceptual and procedural domains and the test items were also calculated, as shown in **Table 7**, **Table 8**, and **Table 9**.

It is evident from **Table 7** and **Table 8** that most of test items in their conceptual and procedural dimensions

Table 10. Performance in conceptual gains stratified by group & gender

Groups	n	Gender	Pre-test		Post-test		Cohen's d*
			Mean	SD	Mean	SD	
EG	25	Male	8.96	2.45	14.96	1.51	2.94
	20	Female	8.80	2.39	13.80	2.37	2.10
	45	Total	8.88	2.40	14.44	2.00	2.51
CG	25	Male	9.08	2.27	10.24	2.74	0.46
	20	Female	8.75	2.40	11.65	3.06	1.05
	45	Total	8.93	2.31	10.86	2.94	0.73

Note. *d: Effect size

Table 11. Paired-sample t-test of conceptual items based on EGs & gender

	Pre-/post-test for EGs						
	Pre-test		Post-test		t	df	Sig.
	Mean	SD	Mean	SD			
EGs	8.88	2.400	14.44	2.000	-12.4	44	0.000
	Pre-/post-test for two gender of EGs						
	Pre-test		Post-test		t	df	Sig.
	Mean	SD	Mean	SD			
Male	8.96	2.45	14.96	1.51	-12.0	24	0.000
Female	8.80	2.397	13.80	2.006	-6.31	19	0.000

were associated with the overall score, with a statistically significant correlation at level of significance 0.01, except for questions 4 and 12. Given high and significant correlation indices, the test was considered to have internal consistency appropriate for this study.

FINDINGS

Results of Research Question One

"Is any statistically significant difference in performance regarding conceptual understanding in NSLOM between students who studied through CSs within scientific inquiry instruction and those who studied through traditional face-to-face teachings?" Conceptual questions required students to think conceptually about the behavior of variables under specific circumstances and how changes in one parameter would affect other parameters or how a concept was related to particular conditions. Students who evoke an idea without understanding its meaning will have difficulty finding the right solution. The conceptual test consisted of eight MCQs.

Table 10 shows that the students in the CGs (mean [M]=8.93, standard deviation [SD]=2.31) and EG (M=8.88, SD=2.40) had the same performance in the conceptual pre-test. There was a higher mean in the conceptual post-test of the CGs and EGs with (M=10.86, SD=2.94) and (M=14.44, SD=2.00), respectively. With Cohen's "**d**" effect size calculation, it indicated that compared to the medium effect of face-to-face instruction (d=0.73), the CSs within an IBL environment had the most considerable effect in enhancing students' understanding of concepts (d=2.51) (**Table 10**).

Overall, the results indicated that the CSs within an IBL environment significantly enhanced students' conceptual understanding of NSLOM topics compared to face-to-face instruction.

A paired-sample t-test was conducted to check whether there was a significant difference between the mean of pre-test and post-test scores for the EGs in the conceptual domain. **Table 11** shows a substantial difference between the mean of pre- and post-test scores in the EGs, which can be reported as $t(44)=-12.4$, $p<0.05$. In the EGs, the findings indicated that using CSs within an IBL environment improved female performance on NSLOM conceptual domain $t(19)=-6.31$, $p=0.000$ ($p<0.05$) and d=2.10, i.e., a large effect size. Additionally, the findings of the male group indicated that using CSs improved male performance on NSLOM conceptual domain $t(24)=-12.0$, $p=0.000$ ($p<0.05$), d=2.94 (large effect size). The results suggest that CSs within an IBL environment helped students to improve their understanding of NSLOM conceptual topics.

Results of Research Question Two

The procedural questions of the test concentrated on procedural knowledge. Students were asked to think clearly about the constraints and the structure of the questions and explain how to obtain answers from the constraints through various steps. Procedural questions focused on assessing students' deep understanding of the procedures and their application. The complexity of procedural problems varies considerably. For example, some problems require only one or two steps, while others require many different procedures. The procedural section of the test consisted of eight MCQs.

Table 11 shows that the students in the CGs (M=8.58, SD=2.24) and EGs (M=9.11, SD=2.43) performed similarly in the procedural pre-test. There was a higher mean in the procedural post-test of the CGs and EGs

Table 12. Performance in procedural gains stratified by group & gender

Groups	n	Gender	Pre-test		Post-test		Cohen's d*
			Mean	SD	Mean	SD	
EG	25	Male	9.08	2.08	11.00	2.27	0.88
	20	Female	9.15	2.87	11.15	2.70	0.72
	45	Total	9.11	2.43	11.06	2.44	0.80
CG	25	Male	8.68	2.30	8.64	2.44	0.02
	20	Female	8.45	2.21	10.45	2.87	0.78
	45	Total	8.57	2.24	9.44	2.76	0.34

Note. *d: Effect size

with (M=9.44, SD=2.77) and (M=11.07, SD=2.44), respectively. Overall results indicated that the CSs within an IBL environment significantly changed students' procedural understanding of NSLOM compared to face-to-face instruction. With Cohen's d effect size calculation, it indicated that, compared to the small effect of face-to-face instruction (d=0.34), acceptance of the simulation had the most significant impact on enhancing students' understanding of the procedural concepts (d=0.80) (**Table 11**).

Table 11 shows that the male students in CG (M=8.68, SD=2.30) and EG (M=9.08, SD=2.08) performed similarly in the pre-test. It was also found among the female students of CG (M=8.45, SD=2.21) and EG (M=9.15, SD=2.87). The results showed that the CSs, within an IBL environment, greatly affected males (d=0.88) and females (d=0.72).

Table 12 shows a statistically significant difference between the pre-test and post-test scores of the EGs, which can be reported as, t(44)=-3.86, p<0.05. In EGs, the results showed that the use of CSs within an IBL environment improved female performance in procedural knowledge t(19)=-2.35, p=0.029 (p<0.05) and d=0.72, which is a moderate effect. Furthermore, the results of the male group revealed that the use of CSs within an IBL environment improved the performance of male students in the NSLOM procedural knowledge t(24)=-3.07, p=0.005 (p<0.05), d=0.88 (significant effect). These results suggested that CSs within an IBL environment enhanced male and female students' procedural knowledge of NSLOM.

Overall, for the female students, these findings demonstrated that using CSs within an IBL environment improved female performance in the NSLOM procedural domain. For the male students, these findings confirmed that applying CSs within an IBL environment significantly impacted males' procedural knowledge. Additionally, it was clear that, when using CSs within an IBL environment, the difference in the performance of male students' procedural knowledge was more significant than that of female students.

DISCUSSION AND CONCLUSIONS

The results of this study suggested that students who learned about NSLOM using CSs as tools within an IBL environment had a better conceptual and procedural understanding of NSLOM than students who had face-to-face instruction. Paired sample t-test and the effect sizes also revealed that both male and female students benefited more from CSs within an IBL environment in NSLOM conceptual and procedural domain. Students' conceptual and procedural understanding was enhanced as CSs engaged students through the interactive visual environment in which students had opportunities to interact and actively manipulate the experimental settings. Students manipulated the parameters and used the results of the manipulation to construct new meanings constructively (Couch, 2014; Seoane et al., 2022; Wieman et al., 2010). In addition, this study demonstrated that through the use of CSs, male students improved more in their conceptual understanding than female students. After initially needing to catch up in conceptual understanding, female students caught up with their male peers with the help of CSs. Despite using CSs, the impact on the procedural understanding needed to be improved more compared to the conceptual understanding. Male and female students were reported to have smaller and medium effect sizes.

When examining female performance in science, it is evident that males are still doing better than females in their ability to think like scientists (OECD, 2015a). this has been attributed to biological differences, such as quantitative skills and spatial visualization (Kahle,1994). In addition, students' confidence may be another reason; science and physics knowledge could be acquired through being engaged in trial and error, which is easier when students are more confident (OECD, 2015a). It may also be related to the increased level of student engagement, which is why EGs had a significantly higher success rate than CGs. However, recent international comparative studies such as PISA and TIMSS have revealed different results and that the gender gap varies based on the type of problem or situation males and females face. CSs have provided students with tools to make NSLOM learning more engaging and effective. It is plausible that multiple representations in PhET simulations helped students to understand concepts through the visual image channels. Therefore, CSs can provide learning opportunities for students to communicate and interact more with each other and the content. Such better interactions can lead to a better understanding of conceptual and procedural knowledge. Furthermore, implementing CSs within an IBL environment could explain the statistically significant performance of EGs compared to CGs. Students could acquire and integrate NSLOM concepts via inquiry-based instruction, which provided them with extensive and varied activities to learn NSLOM.

The results of this study were consistent with several previous studies on the effects of CSs on physics student performance, including those reported by Faour and Ayoubi (2018), Finkelstein et al. (2005a, 2005b), Hazelton et al. (2013), Kumar (2018), and Zacharia and Anderson (2003). Their research suggested that CSs can improve conceptual and procedural understanding and promote students' physics learning. The results of this study also supported the findings of Adam et al. (2020), Jimoyiannis and Komis (2001), and Nestel et al. (2011); their research suggested that CSs can improve procedural understanding and help students overcome cognitive limitations. Moreover, the results of this study were similar to those of Kollöffel and de Jong et al. (2013); their research showed significant progress in students' conceptual and procedural understanding and improved assessment performance.

Limitations

There are some limitations to this study that should be taken into considered. To begin, the majority of the participants were Emirati eleventh-grade male and female students from schools in one city in UAE. While participants were assigned to either the simulations or CGs at random, the convenient sampling procedure and small sample size may limit the findings' generalizability to other grade and ability levels of students. Moreover, despite studying the same topic and following the same study plan, the students were taught by different teachers (i.e., male and female teachers). This could have influenced the results by introducing some variability in the instructional approach. Furthermore, the study employed PhET simulations to teach NSLOM, which is not unique.

Implication and Recommendations

This study has shown that CSs can improve student performance. CSs within an IBL environment had more effect on physics performance than face-to-face instruction. As a result, decision-makers and schools should gradually move towards CSs integration to improve students' understanding. In addition, this study showed how CSs could be helpful for teachers as they could be considered an alternative tool in teaching physics. CSs enhance students' confidence in the classroom, boost their attitudes toward physics, make physics more enjoyable, and enrich students' knowledge, which could be helpful for more upper-level physics classes.

Moreover, unmotivated students challenge teachers in the classroom; Besides their dislike of physics, these students have poor skills, which also demotivates them (Asikhia, 2010). With the use of CSs, teacher-centered classrooms can be transformed into student-centered classrooms, where students can be more engaged and instructions are more task-oriented (Jacobs et al., 2016). Despite this, interactive CSs should be different from traditional experimental laboratories or the role of teachers. Teachers should use it as a tool to improve students' performance.

Future Research Opportunities

Given several studies that supported the effectiveness of CSs on learning, researchers are looking to explore how CSs could influence the development of these much need skills in schools. Moreover, the results need to be treated with appropriate caution. In the long-term future, similar studies will provide further insights into the interpretation of this study. Future studies are also required to comprehensively understand NSLOM topic by expanding the sample to include additional classes and educational levels, such as preparatory and higher education in private and public institutions. Studies with a larger sample size conducted in various international settings are also required to fully comprehend educational programs that integrate inquiry-based pedagogy with interactive computer-based simulations.

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