CONHECIMENTO & DIVERSIDADE
ISSN 2237-8049
UnilaSalle Editora

ENHANCING PHYSICS EDUCATION: THE IMPACT OF COMPUTER SIMULATORS ON STUDENT PERFORMANCE AND CONCEPTUAL UNDERSTANDING

APRIMORAMENTO DO ENSINO DE FÍSICA: O IMPACTO DOS SIMULADORES DE COMPUTADOR NO DESEMPENHO E NA COMPREENSÃO CONCEITUAL DOS ALUNOS

Manar Ben Boumediane
Equipe de Recherche en Ingénierie Pédagogique et Didactique des Sciences (ERIPDS), Université Abdelmalek Essaadi, Morocco
m.benboumediane@gmail.com

Ounaima Azzi
Equipe de Recherche en Ingénierie Pédagogique et Didactique des Sciences (ERIPDS), Université Abdelmalek Essaadi, Morocco
docouma1@gmail.com

Rachid Janati-Idrissi
Equipe de Recherche en Ingénierie Pédagogique et Didactique des Sciences (ERIPDS), Université Abdelmalek Essaadi, Morocco
r.janati@uae.ac.ma

CONHECIMENTO & DIVERSIDADE
ISSN 2237-8049
UnilaSalle Editora

ABSTRACT

This study delves into the advantages of incorporating computer simulations, mainly the PhET simulator, in instructing Newton's laws in contrast to conventional teaching approaches. The research revealed that students who engaged with the simulator exhibited enhanced comprehension of the Newtonian concepts. Additionally, educators noted the simulator's ease of use and efficacy in conveying Newtonian mechanics. The investigation involved examining 120 students from two schools in Morocco, with one group utilizing computer simulations and the other adhering to traditional teaching methods. The normalized learning gain was computed for each group to gauge the learning impact, demonstrating a statistically significant variance favoring the simulation group. These findings underscore the effectiveness of computer simulations in bolstering students' conceptual grasp of Newton's laws. Teachers expressed contentment with the PhET simulator, highlighting its user-friendly interface and pedagogical effectiveness. By engaging with the simulation, students could visualize and experiment with the abstract principles of Newton's laws tangibly, thereby fostering improved knowledge retention. In conclusion, this study underscores the merits of integrating computer simulations, mainly the PhET simulator, in Newton's laws instruction. These outcomes advocate for digital tools to enhance science education and fortify understanding of fundamental scientific concepts. Computer simulations can be an innovative and efficient pedagogical approach to teaching Newton's laws and other scientific principles. By leveraging simulation technology, educators can create engaging and interactive learning experiences that facilitate deeper comprehension and retention of the scientific tenets among students.

Keywords: Computer simulation, Newtonian mechanics, Newton's laws, conceptual understanding, PhET simulator.

RESUMO

Este estudo investiga as vantagens de incorporar simulações de computador, principalmente o simulador PhET, na instrução das leis de Newton em comparação com as abordagens de ensino convencionais. A pesquisa revelou que os alunos que se envolveram com o simulador apresentaram maior compreensão dos conceitos newtonianos. Além disso, os educadores observaram a facilidade de uso e a eficácia do simulador na transmissão da mecânica newtoniana. A pesquisa envolveu o exame de 120 alunos de duas escolas no Marrocos, sendo que um grupo utilizou simulações computadorizadas e o outro aderiu aos métodos tradicionais de ensino. O ganho de aprendizado normalizado foi calculado para cada grupo a fim de avaliar o impacto do aprendizado, demonstrando uma variação estatisticamente significativa a favor do grupo de simulação. Essas descobertas ressaltam a eficácia das simulações de computador para reforçar a compreensão conceitual das leis de Newton pelos alunos. Os professores expressaram satisfação com o simulador PhET, destacando sua interface fácil de usar e sua eficácia pedagógica. Ao se envolverem com a simulação, os alunos puderam visualizar e experimentar os princípios abstratos das leis de Newton de forma tangível, promovendo assim uma melhor retenção do conhecimento. Em conclusão, este estudo ressalta os méritos da integração de simulações de computador, principalmente o simulador PhET, no ensino das leis de Newton. Esses resultados defendem o uso de ferramentas digitais para aprimorar o ensino de ciências e fortalecer a compreensão de conceitos científicos fundamentais. As simulações computadorizadas podem ser uma abordagem pedagógica inovadora e eficiente para ensinar as leis de Newton e outros princípios científicos. Ao aproveitar a tecnologia de simulação, os educadores podem criar experiências de aprendizado envolventes e interativas que facilitam a compreensão mais profunda e a retenção dos princípios científicos entre os alunos.

Palavras-chave: Ly - Dinastias Tran, ideologia humanística, Valores Educacionais, Dai Viet, Vietnã.

Introduction

Today, information and communication technologies, such as computer animations and simulations, are becoming increasingly common in science teaching. Their easy inclusion in school curricula facilitates this integration. Over the last few decades, for example, most science teachers' course materials, whether at high school or higher education level, have now included various simulations in the form of DVDs or URLs from websites (Perkins et al., 2005). Simulation is crucial in science learning, enabling learners to create virtual experiments, control parameters, examine new models, and improve their intuitive understanding of the complex phenomena being studied (Droui et al., 2013). This pedagogical approach also facilitates the implementation of dynamic learning, enabling students to develop sound scientific skills relevant to their future professional careers (De Jong et al., 2013). According to researchers Smetana and Bell (2012), D'Angelo et al. (2014), and Mirana (2016), the use of computer simulation in science learning can improve learners' theoretical understanding, develop their investigative process skills, and build confidence in their learning. It should also be emphasized that these skills enable them to participate actively in the development of society and, above all, to find the best solutions for humanity (Lin et al., 2020).

Due to the inherent limitations of conventional lectures in physics, and especially the need for more scientific laboratory equipment, particularly in Moroccan schools (Chekour, 2015), this constitutes a significant obstacle to carrying out scientific experiments in the classroom. As a result, learners' understanding of the concepts of this subject is becoming increasingly complex, especially as physics is an experimental science (Kane, 2011). It should necessarily be taught by carrying out experiments so that students better assimilate the concepts. This perspective is supported by Cabedo et al. (2018), who believe that science education essentially relies on combining experiments with active, learner-centered teaching methodologies. This promotes the acquisition of general and specific skills. It is within this logic of improving pedagogical practices that the present study fits, looking at the teaching of mechanics, specifically Newton's laws, through computer simulation.

Newton's laws are the most important concepts in mechanics. They can be summed up in three principles. The first is the concept of inertia, where the resultant of acting forces is equal to zero. In other words, objects tend to maintain their state of motion or rest unless they are subjected to external forces. Newton's second law, also known as the fundamental law of dynamics, highlights the relationship between the resulting motion of an object and the force applied to it. Newton's third law is linked to the fundamental principle of the balance of forces in the universe. In other words, it addresses the concept of action and reaction forces. It explains why objects cannot act alone but only by interacting with other objects (Sari et al., 2021).

As previously mentioned, Newton's laws are paramount in explaining tangible physical mechanisms, and they are incorporated at all educational levels, from elementary school to university (Sornkhatha & Srisawasdi, 2013). Nevertheless, various studies (Obaidat & Malkawi, 2009; Saglam-Arslan & Devecioglu, 2010a) have revealed the existence of misconceptions among students regarding Newton's laws of motion. Faced with this finding, several researchers (Atasoy & Akdenız, 2007; Macabebe, Culaba & Maquiling, 2010; Saglam-Arslan & Devecioglu, 2010b) undertook a practical analysis of the mechanisms of conceptual transformation through instruction dedicated to Newtonian laws of motion.

During the preliminary investigations for the present study, we noticed, through the results found, that our students did not understand the concept of inertia at all. For example, some had difficulty grasping why a moving object continues to move without the continuous application of a force. Regarding Newton's second law, many students found it difficult to calculate force, mass, and acceleration. Others had difficulty establishing the relationship between the force applied to an object and the resulting motion. As for Newton's third law, most had difficulty applying it to specific situations, for example, when practicing the action of an inflatable ball. They had difficulty correctly describing the equal and opposite actions and reactions in this situation.

Moreover, analysis of the physics textbooks made available to these students has shown that notions relating to Newton's laws are treated abstractly, with no interaction. This only enables them to better understand Newtonian principles, except when it comes to memorizing formulas. The main task of physical education researchers is to identify students' difficulties in learning the conceptual foundations of physics and to propose remedies to overcome them (Mico et al., 2010). Thus, searching for an effective solution to the problems identified by our students becomes necessary.

In order to deconstruct students' misconceptions and foster the emergence of better ones, a new pedagogical approach has emerged thanks to the advent of Information and Communication Technologies: computer simulation integrated into physics teaching and learning. According to researcher Srisawasdi (2012), this approach is proving particularly effective in inducing conceptual change in students during simulation-based inquiry-based learning.

In this study, we use computer simulation, specifically the PhET simulator, integrated into the mechanics course taught to students at the Badissi and Mohamed VI high schools in Morocco. The main objective is to enable students to assimilate Newton's laws. The central questions of this study are as follows: Is there a statistical difference between conceptual learning of Newtonian mechanics through computer simulation and the traditional approach? Which of these two teaching methods do students prefer? What are the opinions of the teachers consulted for this study concerning the pedagogical effectiveness of the PhET simulator used throughout?

Method

Search type

The present research is exploratory, mixed, multi-case, and multi-site (Grimes & Warschauer, 2008) and quasi-experimental (White & Sabarwal, 2014). The study focuses on quantitative and qualitative variables related to an individual under study. For this study, it is a mixed method, facilitating data collection through questionnaires and semi-structured interviews. It is also multi-case and multi-site, focusing on two Moroccan schools in the Tétouan region (Lycée Badissi and Lycée Mohamed VI) with diverse student populations. In other words, the data for this study were collected from several class groups, called cases, and from several schools or sites. Our research is also of a quasi-experimental type, especially as we seek to examine the impact of computer simulation in physics learning.

Study process and data analysis tools

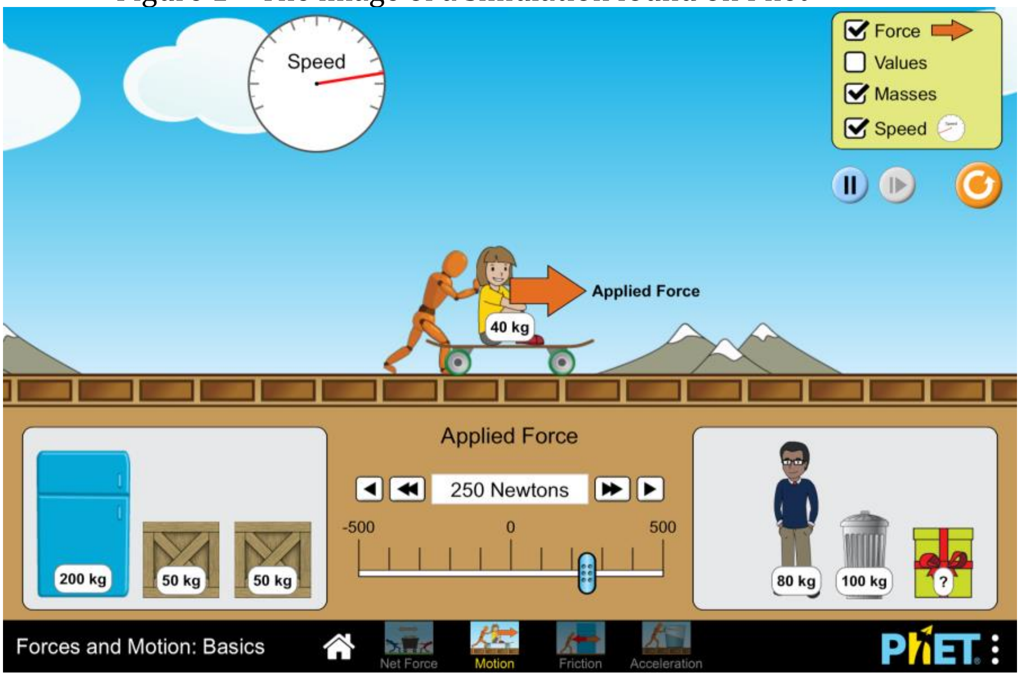
This study was conducted during the 2022-2023 school year, precisely between September and November 2023, at the schools mentioned. One hundred twenty students enrolled in the first year of the baccalaureate in physical sciences, i.e., 60 students per lycée, took part in the study. To ensure the success of our study at each experimental site, we divided the participants into two groups: the control group (GE, n = 30) and the experimental group (GT, n = 30). It should be noted that we randomly assigned students to these groups. Concerning mechanics, students in the control groups were taught using traditional methods, while those in the experimental groups were taught using computer simulations. The simulations used were based on those offered on the platform (https://phet.colorado.edu/fr/simulations/forces-and-motion-basics). See Figure 1. It should be pointed out that we benefited from the assistance of a panel of 20 physics teachers who accompanied us throughout our experimental sessions.

To evaluate the academic performance of the different study groups, we first distributed the pre-test to assess initial differences between the groups. Then, at the end of the learning session, we administered a post-test of 6 multiple-choice questions to each group. The results of these two tests (pre-test and post-test) were then compared to determine each group's progress.

In order to deepen our understanding of the results of the experiment we carried out and to add a more qualitative dimension to them, we organized semi-directive interviews with the teachers (n = 20, divided as follows: 8 women and 12 men) who had guided the experimentation session of the simulations used. These exchanges took place via the Google Meet platform. They focused overall on the effectiveness, user-friendliness, and pedagogical impact of the simulations used from both the teachers' and students' points of view.

For quantitative data analysis, we used IBM SPSS software, which was crucial for calculating the normality of our data and testing the significance of our results. For qualitative data, on the other hand, we used the coding method (Saubesty-Vallier, 2006). We also called on an experienced coder to assist us in this process.

Figure 1 – The image of a simulation found on Phet



Ethical considerations

Before initiating our research, we obtained the permission of our host institutions. We then assured the participants of their free will to participate and the possibility of withdrawing at any time. To this end, we presented them with a consent form, which they signed. We also assured them that their participation in the study would remain anonymous in the study.

To reinforce trust, we established a rigorous framework emphasizing the importance of ethics and confidentiality. This approach is designed to ensure a respectful and transparent study.

Results

In this section, we analyze and interpret the results of our study, which have been statistically processed according to the specific problems addressed.

Verification of the normality of students' pre- and post-test results (Shapiro-Wilk).

a. **Lycée Mohamed VI students' results**

Table 1 – Normality test of pre-test and post-test scores for both groups

Control group (n=31)			
Tests	Average out of 20 points	P-value	Comments
Pre-test	8,5645	0,005	Not significant
Post-test	10,8065	0,100	Significant
Experimental group (n= 31)			
Pre-test	8,5161	0,019	Not significant
Post-test	15,7903	0,315	Significant

The results in Table 1 indicate that the pre-test data do not follow a normal distribution, as demonstrated by the Shapiro-Wilk tests. In contrast, the post-test data for the control and experimental groups appear to converge toward a normal distribution. Since our data set does not show a normal distribution, we used a paired non-parametric test, such as the Wilcoxon signed-rank test, to assess the differences between the data from these two groups.

Analysis of pre-test results for the experimental group versus the control group

Table 1 shows that the pre-test averages for these two groups are 8.5645 for the control group and 0.0484 for the experimental group, respectively, with an absolute score difference of 0.322610 between the two groups on this test. This means there is no significant difference between the pre-test performance of these two groups. In other words, the students had virtually the same knowledge level before the computer simulation learning session started. These results concur with those of Kabigting (2021).

Analysis of post-test results for the experimental group versus the control group

Table 1 shows that the post-test averages for the experimental and control groups are 15.7903 and 10.8065, respectively. With a p-value greater than 0.05, this indicates that there is a significant difference between their post-test scores. In other words, these results show that students in the experimental group performed better in terms of retention of mechanics concepts during their computer simulation learning session (offered on the Phet.com website) than those in the control group who used the conventional teaching method. These results align with other studies (Mahdi et al., 2018; Droui & El Hajjami, 2015), which have shown that computer simulation positively impacts student learning compared with the traditional method.

a. LYCEE BADISI students' results

Table 2 – Normality test of pre-test and post-test scores for both groups

Control group (n=31)			
Tests	Average out of 20 points	P-value	Comments
Pre-test	10,0161	0,107	Significant
Post-test	12	0,607	Significant
Experimental group (n= 31)			
Pre-test	10,532258	0,006	Not significant
Post-test	15,0484	0,019	Not significant

The results presented in Table 2 show that pre-test and post-test data for the control group follow a normal distribution. In contrast, the experimental group's data do not follow a normal distribution. Given these results, we used the Wilcoxon signed-rank test to compare changes between these two matched groups after their learning session.

a. Conceptual investigation in mechanics

As mentioned above, this survey was based on a post-test comprising six validated multiple-choice questions designed to assess students' knowledge of mechanics-related topics (the Government of Manitoba, 2013). However, we resorted to standardized gain to assess students' scores on the said test (Hake, 1998). The latter defined three levels of g: low [0-0.3], medium [0.3-0.7], and high [0.7-1.0]. Hake's gain consists of a normalized gain calculated as follows:

$$a = \frac{actual\ gain}{Max.possible} = \frac{posttest - pretest}{Max.score - pretest}$$

"g" measures the percentage improvement in the post-test score compared to the pre-test score. This is based on the maximum possible improvement score. In other words, this gain refers to the improvement due to the improvement that took place between the pre-and post-tests.

Table 3 – Normalized group gain results

Tests	Lycée BADISI	Lycée Mohamed VI
Expérimental Group	0.4763 or 47.63	0.6324 or 63.24
Control group	0.1984 or 19.84	0.1959 or 19.56

Based on the results presented in Table 3, we can conclude that the normalized gains of the experimental groups are higher than those of the control groups (19.84% and 47.63%). Let us compare these results with the normalized gain evaluation criteria described above. The gain factors for the control group are low, while those for the experimental group for these schools are considered average.

1. The results of a comparison of the groups' pre- and post-test scores using the Wilcoxon Test

Table 4 – Results of the Comparison of Pre- and Post-test Group Scores (Lycée Mohamed VI)

	Control group	Experimental group
Statistics Z	-3,469[b]	-4,864[b]
Sig. asymptotic (p)	0,001	0,000

Note: b. Based on negative ranks.

Based on the results in Table 4, the Wilcoxon test was used to assess whether the performance difference between our physics students, mainly mechanics, was significant according to the pre-test and post-test scores of the control and experimental groups. It is clear from Table 4 that there is a significant difference between the post-test scores of the study groups, with very low p-values (Sig. asymptotic) for both groups, i.e., 0.001 for the control group and 0.000 for the experimental group. This reinforces the idea that the simulation intervention in favor of students in the experimental group positively impacted their learning and academic performance. These results also indicate a real difference in the level of understanding between learners who started their learning session with the same level of mechanical knowledge, as shown by the pre-test averages of the two groups. After the experimental group had used the simulation, this difference was not the result of chance but of the effectiveness of the teaching approach used.

Table 5 – Results of Pre- and Post-test Group Scores Comparison (Lycée Badissi)

	Control group	Experimental group
Statistics Z	-2.681[b]	-4,870[b]
Sig. asymptotic (p)	0,007	0,000

Note: b. Based on negative ranks.

The results in Table 5 indicate statistically significant differences between students' performance in the experimental and control groups, both at pre-test and post-test. For the control group, the Z value is -2.681, with a significant p-value (0.007 < 0.05). Similarly, for the experimental group, the Z value is even lower, at -4.870, with a significant p-value (0.000 < 0.05). In summary, these results reveal a significant improvement in the performance of Badissi high school students at the post-test, suggesting the effectiveness of the pedagogical approach used for this group.

Results of a semi-structured interview with teachers who attended the various simulator testing sessions.

1. How useful is this simulator for the students and for you, the teacher, in carrying out this lesson?

"Yes, using this simulator during physics class has been beneficial for both our students and us teachers" (Responses from 17 teachers compiled).

If the answer is yes, then tell us how it's useful for the students? and how it's useful for you, the teacher?

For students:

Respondents thought that the simulator used during the physics course was useful for students, particularly for the following reasons:

"*With this simulator, students could interactively learn certain mechanics concepts, such as speed and acceleration. This occurred in a user-friendly virtual environment where they attempted to solve exercises by formulating and testing hypotheses. Afterward, they visualized the results of their experimentation in real-time*." (Responses from 16 teachers compiled).

For teachers:

Respondents also felt that the simulator was of great benefit to them:

"*Using this simulator made the physics teacher's job easier. The simulation enabled the teacher to simplify the delicate concepts to be taught. It added a slightly more real dimension to the lesson being taught. This pedagogical approach kept the students engaged in learning mechanical concepts (...)*". (Response from 14 teachers compiled).

2. Does this simulator enable students to learn the various mechanical concepts effectively?

"This simulator enabled the students to learn the concepts studied in class during the experiment effectively. Indeed, the students answered the questions very well during the formative evaluation, sometimes with greater precision. However, this will be verified after correcting the post-tests they had to take at the end of their session learning mechanics on the simulation." (Response from 15 teachers compiled).

3. Did you encounter any difficulties or problems while using this simulator? If so, which ones?

For this question, most teachers said they had no difficulty using the simulator:

"No technical difficulties were encountered with this simulator. The experimenters had provided us with a user guide to help us master it." (Response from a teacher coded E12).

4. How do you find the working environment (buttons, functions, other objects represented on this software, its operation and role) on this simulator is directly and easily understandable by the user?

According to the teachers, the simulator used is user-friendly. Here are a few responses showing how they describe it:

"*Yes, this simulator is very user-friendly. In fact, its interface is flexible and easy to use*... (E1);

This simulator is so easy to use that it helps to reinforce students' commitment to learning (E4)."

5. What do you think of the simulator's operating conditions? What do you think are the ideal conditions of use?

As for the conditions of use of this simulator, respondents felt that a clear protocol for pedagogical use was needed to make the most of its advantages. Some felt that it would be ideal to train teachers in the pedagogical use of this tool. Here is the verbatim summary:

"*Ah, having an excellent pedagogical protocol for successful integration is essential. Having a usage scenario or a pedagogical sheet to facilitate its use is ideal (E6). Teachers should first take a techno-pedagogical training course on integrating computer simulation into teaching (E9*).

6. Does this simulator increase learners' motivation to learn mechanics? Please support your answer with concrete examples.

In response to this question, the teachers were unanimous: their simulator increases their students' motivation. Here is an extract from their answers:

"*Yes, it is a good tool for motivating learners to learn mechanics. First and foremost, it is user-friendly and interactive. Repetitive simulations can only increase their desire to learn the subject, whether in the classroom or at home. What is more, having the results of their simulations immediately available can also be an additional motivating factor...*" (14 teachers).

Discussion

The positive responses provided by the 17 teachers indicate that integrating the simulator during the teaching of mechanics was highly beneficial for both students and teachers. Indeed, these responses highlight the advantage of computer simulators as educational tools that enhance and enrich students' conceptual learning experience and facilitate teachers' work in this context. This reinforces the idea that computer simulations can be an alternative pedagogical means to help students develop a better functional understanding of physics (Jimoyiannis & Komis, 2001).

Teachers emphasize that the simulator has enriched their students' learning experience by providing an environment conducive to interactivity, experimentation, hypothesis formulation, and real-time visualization of the results of their simulations (Boumediane et al., 2023). This can help establish more dynamic learning to understand mechanics concepts better. These results make sense, especially as this teaching/learning approach helps students improve their understanding of mechanics concepts (Deliktaş, 2011).

About the benefits they have derived from using the simulator in physics teaching, teachers perceive the simulator as a tool that simplifies the teaching of abstract, delicate, and complex concepts to be assimilated by students (Boumediane et al., 2022). This is because computer simulation brings a realistic dimension to lessons, and above all, it keeps learners engaged, even increasing their motivation for mechanics (De Freitas, 2006).

Faced with whether this simulator has enabled students to learn the various mechanics concepts effectively, the teachers feel that this will depend on the results of the post-tests to confirm the preliminary findings. Given that the results of the post-tests lean in favor of the experimental groups, we can affirm that the said simulator positively impacted their students' learning of mechanics. The computer simulator can be considered an effective didactic tool in teaching mechanics. These results concur with those of the study presented by Liao and Liu (2020).

The results show that most teachers experienced no technical difficulties when using the simulator. This can be attributed to the preparation and support provided by the experimenters before the start of the session on learning mechanics concepts with high school students. It is also important to note that the teachers' mastery of this tool is a positive aspect of successfully integrating the simulator into the educational context. The simulator's user-friendliness and ease of use are essential factors in its educational integration, as expressed by teachers E1 and E2.

We can see that respondents consider the conditions of use of the simulator to require a clear pedagogical protocol to derive maximum benefit from it. This means it is essential to have a detailed integration and use scenario to make the most of this tool in the classroom. To achieve this, it is imperative to train teachers in using computer simulation to be ready to take up such a pedagogical challenge. This is because, during the learning session, some teachers found it difficult to effectively integrate simulation into their lesson sequence, as in their basic training, they needed to prepare to use such an approach. According to Karsenti and Gauthier (2006), lack of teacher training is one of the key factors hindering the integration of ICT in the classroom.

Responses to the question on the simulator's impact on student motivation highlight the positive role of the Phet simulator in motivating students, highlighting the specific features that make it effective as an educational or didactic tool. These include user-friendliness, interactivity, repeatable simulations, and immediate feedback. All these features are crucial in increasing learner motivation to learn mechanics. They also help to create a stimulating learning environment for students. Guided pedagogical activities in computer simulation can serve as an alternative to motivate students in their learning (Gokhale, 1996).

Conclusion

At the end of our research activities on the integration of computer simulation into the teaching of mechanics delivered to the high school students involved in our study, we can confirm that both at Lycée Badissi and Lycée Mohamed VI, computer simulation improved learners' performance in their learning of mechanical concepts compared to the traditional paper-and-pencil activity-based method, which physics teachers regularly use.

From a pedagogical point of view, students prefer computer simulation to other teaching methods used in physics. This approach proved to be genuinely motivating for them in their learning of mechanics. They were fully committed to learning through computer simulation. This improved their understanding of mechanical concepts, which lectures still needed to explain.

From a technical point of view, the study's conclusions suggest that computer simulation is an approach that offers students a hands-on, participatory experience based on constructivism. It also provides them with direct, dynamic feedback, helping them to make explicit models or physical phenomena that are complex to assimilate and otherwise inaccessible.

Recommendations

Through its various results, the present study has shown that using the PhET computer simulator in teaching/learning physics, mainly mechanics can effectively improve students' performance in this subject. We strongly appeal to decision-makers and schools to migrate towards such an approach by appropriating the PhET tool. This tool will help improve students' conceptual understanding.

What is more, the teachers who took part in this study see it as an effective way of alternating theory and practice in physics teaching, showing that it is a tool that could be useful for both teachers and students.

Integrating this pedagogical tool or approach in Moroccan high schools would enable the physics teacher to focus his teaching on the students rather than himself. In this context, students are called upon to discover the expected knowledge independently, with the teacher instructing them to guide them through the tasks (Jacobs et al., 2016).

Study limits

This study has several limitations that need to be taken into account. Firstly, the participants all came from the same Moroccan region, Tétouan. Secondly, the small size of our sample may limit the generalizability of the results at national and even international levels. We also aimed to prepare various pedagogical sheets to facilitate teachers' use of PhET during physics lessons. However, we could not achieve this objective due to time, financial, and logistical constraints.

These limitations pave the way for further research in computer-assisted learning. Thus, future investigations should be based on a more extensive and diversified sample to better generalize results at national and international levels. Researchers should also consider producing pedagogical fact sheets to facilitate the use of simulation in the classroom.

REFERENCES

Alabidi, S., Alarabi, K., Tairab, H., Alamassi, S., & Alsalhi, N. R. (2023). The effect of computer simulations on students' conceptual and procedural understanding of Newton's second law of motion. Eurasia Journal of Mathematics, Science and Technology Education, 19(5), em2259. https://doi.org/10.29333/ejmste/13140

Atasoy, Ş., & Akdeniz, A. R. (2007). Newton'un Hareket Kanunları konusunda kavram yanılgılarını belirlemeye yönelik bir testin geliştirilmesi ve uygulanması. Journal of Turkish Science Education, 4(1), 45–59.

http://www.tused.org/index.php/tused/article/download/658/564

Bayrak, B. (2007). TO COMPARE THE EFFECTS OF COMPUTER BASED LEARNING AND THE LABORATORY BASED LEARNING ON STUDENTS' ACHIEVEMENT REGARDING ELECTRIC CIRCUITS. Turkish Online Journal of Educational Technology, 6(1), 15–24. http://files.eric.ed.gov/fulltext/ED500072.pdf

Bertacchini, F., Bilotta, E., Caldarola, F., & Pantano, P. (2018). The role of computer simulations in learning analytic mechanics towards chaos theory: a course experimentation. International Journal of Mathematical Education in Science and Technology, 50(1), 100–120. https://doi.org/10.1080/0020739x.2018.1478134

Bouffy, H. D. E. (2022). L'intégration des TIC dans la formation des enseignants au Maroc: analyse documentaire des réformes éducatives The use of TIC in teachers training in Morocco: documentary analysis of educational reforms. HAL (Le Centre Pour La Communication Scientifique Directe). https://doi.org/10.5281/zenodo.7158416

Boumediane, M. B., Benabdelouahab, F., & Idrissi, R. J. (2022). TEACHING OF PHYSICAL SCIENCES IN MOROCCAN COLLEGES: THE OBSTACLES AND DIFFICULTIES ENCOUNTERED. 14(1).

Boumediane, M. B., Janati-Idrissi, R., & Benabdelouhab, F. (2023). PROFILING OF MOROCCAN HIGH SCHOOL PHYSICAL SCIENCE TEACHERS FOR IN-SERVICE TRAINING IN ICT: A CROSS-SECTIONAL EXPLORATORY STUDY. International Journal of Education, Technology and Science, 3(4), Article 4.

Cabedo, L., Royo, M., Miravet, L. M., & Guraya, T. (2018). University Social Responsibility towards Engineering Undergraduates: The Effect of Methodology on a Service-Learning Experience. Sustainability, 10(6), 1823. https://doi.org/10.3390/su10061823

Chekour, M. (2015). Les facteurs influençant l'acquisition des concepts en électricité. Cas des lycéens marocains. Adjectif.net. https://adjectif.net/spip.php?article354

D'Angelo, C., Rutstein, D. W., Harris, C., Bernard, R., Borokhovski, E., & Haertel, G. D. (2014). Simulations for STEM learning: Systematic review and meta-analysis. SRI Education. https://experts.illinois.edu/en/publications/simulations-for-stem-learning-systematic-review-and-meta-analysis

De Freitas, S. I. (2006). Using games and simulations for supporting learning. Learning, Media and Technology, 31(4), 343–358. https://doi.org/10.1080/17439880601021967

De Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. Science, 340(6130), 305–308. https://doi.org/10.1126/science.1230579

Deliktaş, B. (2011). Computer technology for enhancing teaching and learning modules of engineering mechanics. Computer Applications in Engineering Education, 19(3), 421–432. https://doi.org/10.1002/cae.20321

Droui, M., & El Hajjami, A. (2015). Simulation et apprentissage par investigation [Article]. In www.est-usmba.ac.ma (Vol. 1). http://www.est-usmba.ac.ma/conferences/apel2015/proceeding/docs/E15C08.pdf

Droui, M., El Hajjami, A., Bouklah, M., & Zouirech, S. (2013). Impact de l'apprentissage par problème sur la compréhension conceptuelle de la mécanique newtonienne. EpiNet, 157. https://edutice.hal.science/edutice-00940669/file/a1309d.htm

El HASSOUNY, E. H., KADDARI, F., Abdelrhani, E., & Habibi, I. (2015). LOGICIEL DE SIMULATION "DYNAMIC" ET APPRENTISSAGE DE LA MECANIQUE NEWTONIENNE EN DEUXIEME ANNEE BACCALAUREAT. American Journal of Innovative Research and Applied Sciences, 2(5), 210–220. https://www.american-jiras.com/El%20Hassan%20%20ManuscriptRef.2-ajiras050616.pdf

Gokhale, A. A. (1996). Effectiveness of computer simulation for enhancing higher order thinking. Journal of Industrial Teacher Education, 33(4), 36–46. https://eric.ed.gov/?id=EJ527047

Grimes, D., & Warschauer, M. (2008). Learning with Laptops: A Multi-Method Case Study. Journal of Educational Computing Research, 38(3), 305–332. https://doi.org/10.2190/ec.38.3.d

Hake, R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics, 66(1), 64–74. https://doi.org/10.1119/1.18809

Jacobs, G. M., Renandya, W. A., & Power, M. (2016). Simple, powerful strategies for student centered learning. In Springer briefs in education. https://doi.org/10.1007/978-3-319-25712-9

Jimoyiannis, A., & Komis, V. (2001). Computer simulations in physics teaching and learning: a case study on students' understanding of trajectory motion. Computers & Education, 36(2), 183–204. https://doi.org/10.1016/s0360-1315(00)00059-2

Kane, P. S. (2011). Les pratiques expérimentales au lycée- Regards croisés des enseignants et de leurs élèves. Radisma, 7. http://www.fastef.ucad.sn/articles/saliou/article2_pratiques.pdf

Karsenti, T., & Gauthier, C. (2006). Les TIC bouleversent-elles réellement le travail des enseignants? Formation Et Profession, Le Bulletin Du CRIFPE, 12(3). http://www.thierrykarsenti.org/pdf/scholar/ARP-karsenti-32-2006.pdf

e gouvernement du Manitoba. (2013). Physique 12e année Programme d'études: document de mise en œuvre. In www.mtbb.mb.ca (No. 98284). Centre des manuels scolaires du Manitoba. https://www.edu.gov.mb.ca/m12/frpub/ped/sn/phys/dmo_12/pdf/doc_complet.pdf

Liao, Y., & Liu, S. (2020). MechGames: Teaching and Learning Dynamics through Computer Simulations and Games. American Society for Engineering Education. https://cms.jee.org/mechgames-teaching-and-learning-dynamics-through-computer-simulations-and-games

Lin, X. Y., Yang, W., Wu, L., Li-Fen, Z., Wu, D., & Hui, L. (2020). Using an Inquiry-Based Science and Engineering program to promote science knowledge, Problem-Solving skills and Approaches to learning in preschool children. Early Education and Development, 32(5), 695–713. https://doi.org/10.1080/10409289.2020.1795333

Macabebe, E. Q. B., Culaba, I. B., Maquiling, J. T., Paosawatyanyong, B., & Wattanakasiwich, P. (2010). Pre-conceptions of Newton's laws of motion of students in Introductory Physics. AIP Conference Proceedings. https://doi.org/10.1063/1.3479843

Mahdi, K., Laafou, M., & Janati-Idrissi, R. (2018). L'impact de la formation continue à distance des professeurs de physique aux logiciels de simulation informatique. JOURNAL FOR EDUCATORS, TEACHERS AND TRAINERS, 9(1), 27–41. https://jett.labosfor.com/index.php/jett/article/view/179/92

Mico, S., Mandili, J., Tahiri, V., & Muco, R. (Eds.). (2010). Computer simulations enhance qualitative meaning of the Newton's second law. GIREP-ICPE-MPTL Conference 2010. https://www.univ-reims.fr/site/evenement/girep-icpe-mptl-2010-reims-international-conference/gallery_files/site/1/90/4401/22908/29678/29698.pdf

Mirana, V. P. (2016). Effects of Computer Simulations and Constructivist Approach on Students' Epistemological Beliefs, Motivation and Conceptual Understanding in Physics. Social Sciences, Humanities and Education, 89–93. https://doi.org/10.17758/uruae.uh0516087

Obaidat, I. M., & Malkawi, E. (2009). The grasp of Physics Concepts of motion: identifying particular patterns in students' thinking. International Journal for the Scholarship of Teaching and Learning, 3(1). https://doi.org/10.20429/ijsotl.2009.030119

Perkins, K. K., Adams, W. K., Dubson, M., Finkelstein, N. D., Reid, S., Wieman, C., & LeMaster, R. (2005). PHET: Interactive Simulations for Teaching and Learning Physics. The Physics Teacher, 44(1), 18–23. https://doi.org/10.1119/1.2150754

Quels apports du codage des données qualitatives? (2006). In C. Saubesty – Vallier (Ed.), Conférence Internationale de Management Stratégique, Annecy / Genève 13-16 Juin (15th ed., Vol. 2016). https://apprendre.auf.org/wp-content/opera/13-BF-References-et-biblio-RPT-2014/Quels%20apports%20du%20codage%20des%20donn%C3%A9es%20qualitatives%20.pdf

Sağlam-Arslan, A., & Devecioğlu, Y. (2010a). Student teachers' levels of understanding and model of understanding about Newton's laws of motion. Asia-Pacific Forum on Science Learning and Teaching, 11(1). https://www.ied.edu.hk/apfslt/download/v11_issue1_files/arslan.pdf

Sağlam-Arslan, A., & Devecioğlu, Y. (2010b). Student teachers' levels of understanding and model of understanding about Newton's laws of motion. Asia-Pacific Forum on Science Learning and Teaching, 11(1). https://www.ied.edu.hk/apfslt/download/v11_issue1_files/arslan.pdf

Sari, D. P., Widodo, W., & Madlazim. (2021). Computer simulation feasibility for Newton's law learning. Turkish Journal of Computer and Mathematics Education (TURCOMAT), 12(14), 4282–4291. https://www.turcomat.org/index.php/turkbilmat/article/view/11270

Şengüleç, Ö. A., & Azar, A. (2010). Computer-Assisted and Laboratory-Assisted Teaching Methods in Physics Teaching: the Effect on Student Physics Achievement and Attitude towards Physics. Eurasian Journal of Physics and Chemistry Education, 1(1), 43–50. http://www.eurasianjournals.com/index.php/ejpce/article/viewFile/613/pdf_104

Smetana, L. K., & Bell, R. L. (2012). Computer Simulations to Support Science Instruction and Learning: A critical review of the literature. International Journal of Science Education, 34(9), 1337–1370. https://doi.org/10.1080/09500693.2011.605182

Sornkhatha, P., & Srisawasdi, N. (2013). Supporting conceptual development in Newton's laws of motion using an interactive computer-simulated laboratory environment. Procedia - Social and Behavioral Sciences, 93, 2010–2014. https://doi.org/10.1016/j.sbspro.2013.10.157

Srisawasdi, N. (2012). Student Teachers' perceptions of Computerized Laboratory Practice for science Teaching: A Comparative analysis. Procedia - Social and Behavioral Sciences, 46, 4031–4038.

https://doi.org/10.1016/j.sbspro.2012.06.192

White, H., & Sabarwal, S. (2014). Méthodes et modèles quasi expérimentaux. In www.unicef-irc.org/ (No. 8). Centre de recherche Innocenti de l'UNICEF. Retrieved November 20, 2023, from https://www.unicef-irc.org/publications/pdf/MB8FR.pdf