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APPLICATION OF MULTIMEDIA SIMULATIONS FOR ENERGY CONCEPT VISUALIZATION: CHALLENGES AND OPPORTUNITIES

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Abstract- Simulations are increasingly recognized as a valuable educational tool for improving student understanding of complex topics such as energy concepts. However, their integration into Moroccan educational institutions presents unique challenges. This study examines using multimedia simulations in Moroccan secondary education to address these difficulties and improve the teaching of energy concepts. Using a quantitative approach, data were gathered from 68 physics teachers through a questionnaire. Among the participants, 72.1% were men, while 27.9% were women. Regarding the degree of use of simulations, 44.1% of teachers declared using simulations to explain aspects related to the energy concept, whereas only 55.9% of teachers decided not to. Concerning the impact of simulations on student learning about energy aspects, the results recorded demonstrate that most respondents admitted that applying simulations improves students' conceptual understanding of energy-related concepts (M = 4.40, SD = 0.498). In addition, the results have also shown that using interactive simulations in teaching helps to make learning about energy more memorable and understandable for students (M = 4.13, SD = 0.730). Regarding obstacles to integrating simulations into teaching practice, 65.8% of Moroccan physics teachers said that the lack of technological equipment in their schools was the main obstacle, and 34.2% declared that lack of training or familiarity and overcrowded classroom were additional challenges.

Keywords: Interactive Simulations, Energy Concepts, Moroccan Secondary Teachers.

1. INTRODUCTION

According to the latest TIMSS (Trends in International Mathematics and Science Study) survey by the International Association for the Evaluation of Educational Achievement (IEA), Moroccan students recorded poor results and low performance in physical sciences, placing them among the lowest positions in the international assessments. A critical factor contributing to this poor performance is the limited availability of scientific equipment in school laboratories, which hinders the implementation of experimental activities that are considered an essential pedagogical tool in learning fundamental physics concepts. As a result, 68% of teachers are unable to carry out most of the planned experiments due to this lack of equipment [1].

To address the challenges of traditional experimental methods, some researchers have turned to solutions-based ICT (Information and Communication Technology). Bestougeff and Fargette introduced computer-based teaching methods, incorporating computer-assisted experiments (CAEx) along with advanced technologies like augmented reality (AR) and virtual reality (VR) to clarify abstract scientific concepts [2].

Simulation stands out as a particularly effective solution, offering a virtual environment where students can actively engage with scientific concepts. Multimedia simulation is currently considered one of the most powerful applications of ICT in science. Indeed, science teachers can now use advanced multimedia simulation to offer learners the opportunity to observe and manipulate models representing a variety of phenomena and processes. More specifically, it allows learners to animate and simulate real-world processes through "virtual experiments" that might be dangerous, expensive, or impossible in school laboratories [3]. Moreover, the incorporation of computer simulations in the classroom process can increase students' interest in the course and improve learning outcomes [4]. They bridge the gap between students' prior knowledge and learning new physics concepts, helping them gain understanding by actively restating their misconceptions [5]. On the other hand, a study by [6] showed that a teaching strategy that combined simulations with hands-on experiments had a slightly significant effect on student learning compared to a strategy that relied only on practical activities.

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Simulations have been shown to help overcome challenges engineering students face in understanding abstract concept in energy and thermodynamic. Research has shown that these methods, which incorporate computer technology and multimedia to enhance interactivity and visualization, improve student performance and skill development. Feedback from students has been positive and encouraging, highlighting the effectiveness of simulations in education [2].

It is obvious that a solid theoretical basis on the effectiveness of incorporating simulations in science teaching is already established, but unfortunately little research has been carried out on their use in Moroccan science classes especially in teaching courses that cover energy concepts. The mastery of some basic physical concepts, such as the concept of energy, is crucial, especially during secondary education. Numerous studies have shown that some energy-related concepts are considered difficult to teach and are not well assimilated by students. For example, energy conservation principle is commonly taught as energy that cannot be created or destroyed. However, many science educators feel that this explanation may confuse students since it neglects to include concepts such as "energy transfer, energy flow, and energy conversion" [7]. Therefore, the objective of the present article is to examine the degree of incorporating interactive simulations in teaching process especially for chapters related to energy concepts by Moroccan physics secondary teachers. In addition, this research aims to examine teachers' perspectives on the effectiveness and potential benefits of using simulations as an educational tool in teaching and also tries to examine the obstacles that could prevent their integration during lessons.

2. THEORETICAL FRAMEWORK

A simulation is a computer program that includes a simplified system of a process. Scientific numerical simulation is based on the implementation of theoretical models to study the functions and properties of modeled systems and to predict their evolution [8]. Additionally, computer simulation programs can model and simulate a wide range of scientific concepts, scientific experiments and natural phenomena, and have the ability and qualities to promote students' scientific learning [9].

The quality of a learning environment relies on various factors, and successful design requires a blend of didactical, technological, and knowledge expertise [10]. Each of these components must follow specific principles to uphold educational standards and improve learning outcomes. There is also a strong analogy between the work of the teacher and that of cognitive engineer, as both roles focus on designing effective learning experiences [11].

Simulations in the learning environment are student-centered tools that effectively involve the cognitive, psychomotor, and affective aspects of the learning process [12], promoting a holistic approach to science education. From a constructivist perspective, learning is a constant process of both discovery and mastery, which implies that knowledge is built through interaction and manipulation of the environment [13]. Simulations align well with this view by creating dynamic learning spaces that encourage inquiry, hypothesis testing, and reflective thinking key components of scientific investigation [8]. Moreover, interactive simulations support inquiry-based learning, which has been shown to improve students' conceptual understanding by fostering skills such as evidence-based explanation, structured inquiry, and problem-solving [14].

Numerous appearances, controls, visuals, interactivity, and design ideas are used in the available simulations; these are frequently determined only by the creators' preferences or code simplicity. However, little is known about the design items and patterns that are crucial for better usage by and comprehension by students [15].

Educational simulations vary widely in design, often shaped by developers' preferences or code simplicity rather than research-driven principles. However, tools like Phet (The Physics Education Technology) simulations developed by Colorado University which contains a simulation of physics, biology and chemistry learning for the benefit of classroom learning or individual learning [16]. simulation strengthens the link between actual phenomena and the science behind them, reinforces learning using interactive, constructivist methods, which offer feedback and fosters a creative workplace. All these factors tend to mitigate those aforementioned limitations through a structured, research-based design process, as shown in the flow diagram (Figure 1) [15]. This process begins by defining specific learning goals and creating an initial design, followed by iterative user interviews that gather essential feedback. Based on these insights, the simulation undergoes continuous redesign to refine the interface and content for clarity and engagement. The next stage involves testing the simulation in classroom settings, where observations inform any final adjustments needed to meet educational standards effectively.

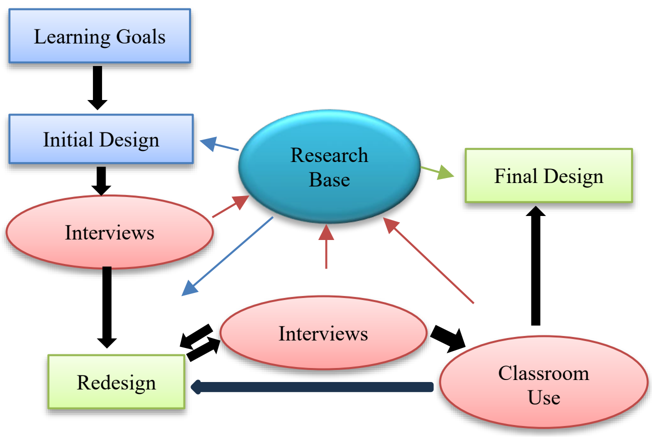

Figure 1. Simulation design process [15]

This systematic design cycle ensures that simulations are both pedagogically sound and user-friendly, enhancing cognitive engagement and supporting science instruction [17], particularly in settings where physical resources are limited. As a result, simulations serve as valuable investigative tools, adaptable to diverse learning environments, and capable of fostering metacognitive and problem-solving skills, thus bridging significant educational gaps in physical science education [18].

2. METHODOLOGY

2.1. The Population of the Study

In the present study, quantitative methods were used through a questionnaire addressed to 120 secondary school teachers in the physics-chemistry discipline belonging to the provincial delegation of Kenitra. But only 68 out of 120 actively responded in the present study.

2.2. Development of the Questionnaire

In order to examine the use of simulations in teaching physics especially the aspects related to energy, a self-designed questionnaire was developed. The survey was available online. It structured into five sections as shown in Table 1.

Table 1. Overview of the used sections

Sections	Number of items	Answer format
1.The personal data of teachers	4	Closed ended
2. The use of hands-on experiments activities and simulations	4	Likert-scale and closed ended
3. Simulation integration in energy courses: pedagogical approaches and objectives	3	Multiple choice and closed ended
4. Barriers to the use of simulations in the teaching practice	6	Multiple choice
5. Effects of interactive simulations on student learning of energy concepts	7	Likert - scale

2.3. Data Analyses

The questionnaire was elaborated and validated before being randomly distributed online with Moroccan physics-chemistry teachers of Moroccan secondary school using the Google-Forms tool. The data was then collected within two months through random sharing, the collected data was coded and analyzed by SPSS software version 21. Thus, Descriptive statistical analysis using frequency, percentage, mean, and standard deviation was used to analyze the statistics collected from the questionnaire.
A Cronbach's alpha was applied to assess the internal consistency reliability of section 5 with a result of α = 0.875, which shows an acceptable internal consistency.

3. RESULTS

3.1. Information about Teachers

In the overall population (n=68) categorized by gender, there are 49 male respondents with a percentage of 72.1% compared to only 19 women with 27.9%, as shown in Figure 2. Our sample is composed mainly of young teachers n=32 (47.1%) has an average age less than 30 years, n=27(39.7%) has an average age between 31 years and 40 years, n=5 (7.4%) has an average age between 41 years and 50 years and only n= 4 (5.9%) are over 51 years old (Figure 3). Regarding school type, Figure 4 illustrates that 33 (48.5%) respondents teach in high school, while 35 respondents (51.5%) teach in middle school.

Concerning the teaching experience of teachers who responded to our questionnaire, 48.5% have less than 6 years of seniority, 29.4% have seniority between 6 and 10 years, 16.2% of the sample have been in teaching between 11 and 20 years, and only 5.9% have than 21 years of seniority. These results could be attributed to the utilization of an electronic questionnaire.

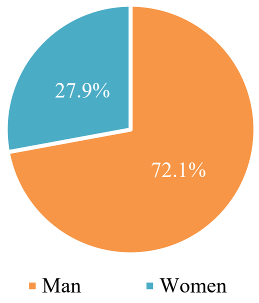

Figure 2. Information about gender of teachers

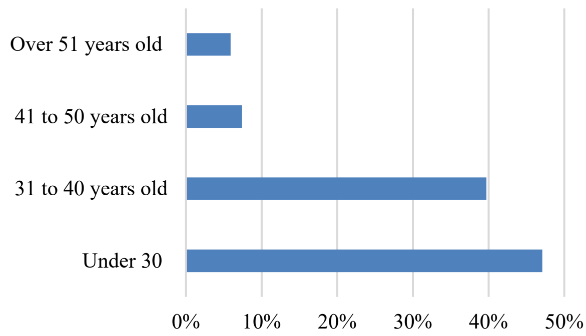

Figure 3. Distribution of teachers by age

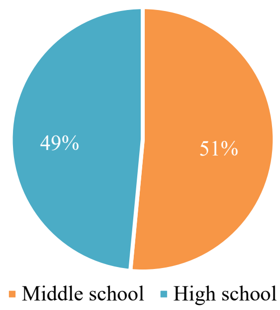

Figure 4. Teachers' type of school

3.2. The Use of Hands-on Experiments and Simulations

3.2.1. The Quantitative Use of Hands-on Experiments

The data collected in Figure 5 showed that most teachers (30.9%; n=21) do not carry out these experimental activities, whereas (20.6%; n=14) declare that they rarely use the experimental activities of the textbook. On the other hand, (23.5%; n=16) tend to use them occasionally. While some others declare that they often carry out these hands-on experimental activities (16.2%; n=11), only (8.8%; n=6) of the teachers use them all the time.

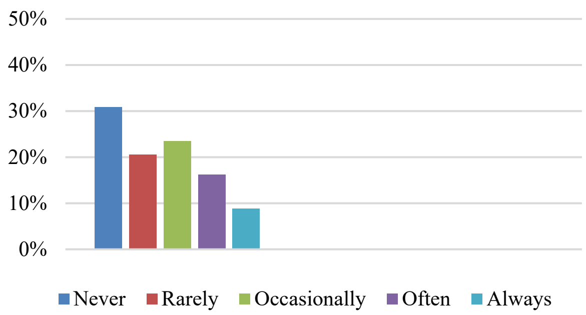

Figure 5. Frequency of hands-on activity usage

3.2.2. The Quantitative Use of Simulations in Teaching Energy Courses

To examine the use of simulations for teaching energy concepts, the degree of incorporating simulations in practice teaching are used as comparison the results showed that (63.2%; *n*=43) of the teachers use simulations in physics classes during their practice teaching, and (36.8%; *n*= 25) do not (Figure 6).

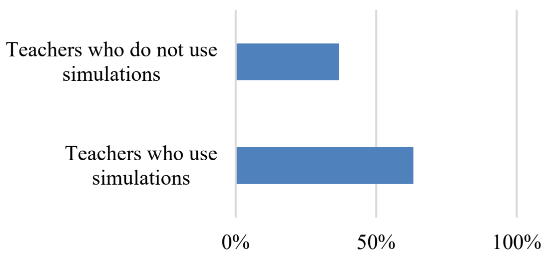

Figure 6. Simulation usage in physics classrooms by teachers

When analyzing these data in accordance with teachers who use simulations for teaching energy chapters, the results in Figure 7 show 44.1% of participants declared (*n*=30) the use of simulations to explain courses related to energy, whereas 55.9% of teachers (*n*=38) do not.

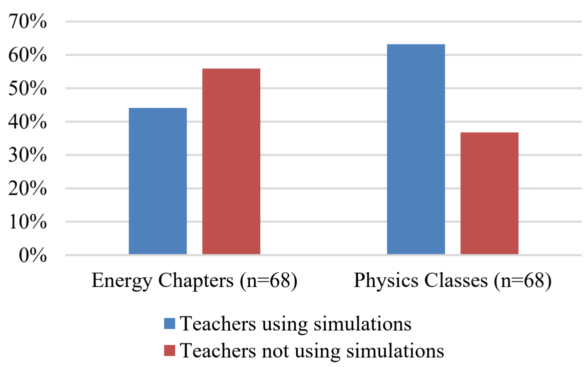

Figure 7. Comparison of simulation use in energy and physics topics

Comparing simulations to hands-on experiments, 53.3% of the surveyed teachers declared (Figure 8) that the interactive simulations are used additionally and not as replacement for hands-on experiments, while 30 % agreed that simulations serve a comparable role to hands-on experiments, and 16.7% of teachers declared that they replace it completely.

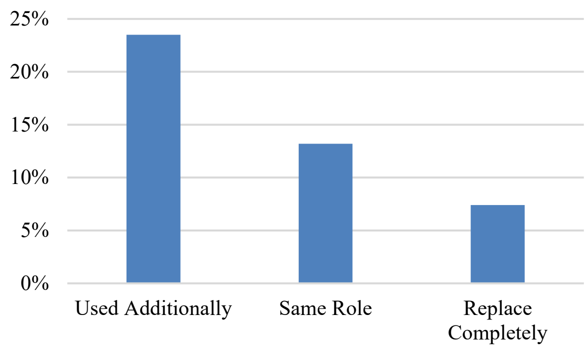

Figure 8. Teachers' perspectives on the role of simulations compared to real-world experiments

3.3. Simulation Course and Pedagogical Objectives

The majority of these teachers declared that they used interactive simulations to present the lesson of mechanical energy of a solid (63.3%; *n*= 19), energy study (56.7%; *n*= 17) and with same percentage (46.7 %; *n*= 14) for both lessons of kinetic energy and transformation of energy, whereas (43.3%; *n*= 13) of teachers declared that they used them to explain the work of a force and potential energy of gravity, while the minority of teachers (33.3%; *n*= 10) used them to explain lessons of energy transfer in an electric circuit, principle of energy conversion in an electrical circuit and for the lesson of electric energy, Table 2.

Table 2. Energy courses

Energy courses	*n*	Percentage %
The mechanical energy of a solid	19	63.3%
Energy Study	17	56.7%
Work and Kinetic Energy	14	46.7%
Energy transformation	14	46.7%
Potential Energy of Gravity	13	43.3%
Concept of the work of a force	13	43.3%
Energy transfer in an electric circuit	10	33.3%
Principle of energy conservation in an electrical circuit	10	33.3%
Electric Energy	10	33.3%

Regarding the pedagogical approaches in which simulations are used, most teachers who opt for simulations in teaching energy concepts have stated that they use them in various ways during their energy lessons. Most of respondents declared 63.3% use the investigation approach when using simulations, 46.7% use them in the problem-solving approach and 40% to verify results and 30% for Consolidation, Figure 9.

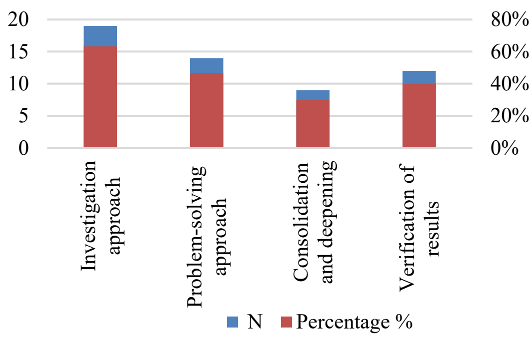

Figure 9. Pedagogical approaches

When teachers were asked whether they had achieved the pedagogical objectives set during the teaching of energy courses using simulations, the results showed in Figure 10 indicate that 93.3% of them stated they had successfully achieved the pedagogical objectives, while 6.7% did not.

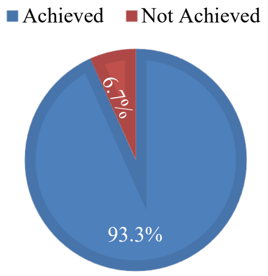

Figure 10. Teachers' view on the use of simulations

3.4. Effects of Interactive Simulations on Student Learning of Energy Concepts

The teachers answered a 6-item questionnaire Table 3 on the effects of interactive simulations on student learning of aspects of energy, each item is represented through a Likert scale with five points that ranges between "Completely disagree" to "Completely agree". The table below presents the responses obtained from each item, categorized by mean and standard deviation. The results indicate that most teachers favor all benefits resulting from the integration of interactive simulations on student learning of energy concepts since the means vary between [4.23; 4.40] out of 5. Most respondents agreed that integrating simulations improves student's conceptual understanding of energy-related concepts ($M = 4.40$, $SD = 0.498$), keep engaged and interested in learning about energy concepts ($M = 4.30$, $SD = 0.535$) and visualize energy-related phenomena ($M = 4.23$, $SD = 0.730$). Furthermore, the majority of teachers noticed that incorporating simulations significantly improved students results in the classroom ($M = 4.23$, $SD = 0.791$) and also reduced the difficulties and misconceptions associated with this concept ($M = 4.17$, $SD = 0.898$). Furthermore, based on the results obtained, it has also been observed by teachers that the implementation of interactive simulations in teaching help to make the study of energy more memorable and understandable for students ($M = 4.13$, $SD = 0.774$).

Table 3. Effects of using simulations on student learning

Items	Average	*SD*
Simulations improve students' conceptual understanding of energy-related aspects.	4.40	0.498
The simulations helped to keep the students engaged and interested in learning about energy concepts.	4.30	0.535
Simulations help to make learning about energy more memorable and understandable for students.	4.13	0.730
Simulations reduce the difficulties and misconceptions associated with this concept.	4.17	0.791
Simulations make it easier for students to visualize energy-related phenomena.	4.23	0.898
The simulations contributed to improved student results.	4.23	0.774

Comparing the mean (*M*) between simulation-based teaching methods and hands-on lab methods in terms of students' engagement (Table 4), the results showed that hands-on lab methods achieved a lower mean student engagement of 2.51, while simulation-based methods showed a mean engagement of 4.30.

Table 4. Comparison between simulations-based teaching method and hands-on lab on student engagement

Teaching methods	Mean	*SD*
Simulation-based	4.30	0.535
Hands-on lab	2.51	1.321

3.5. Barriers to the Use of Simulations in the Teaching Practice

Factors that prevent teachers (sub sample: NOSIM, n=38) from using interactive simulations in their teaching practice with students are summarized in Figure 11. The percentages refer to the respective sub sample.

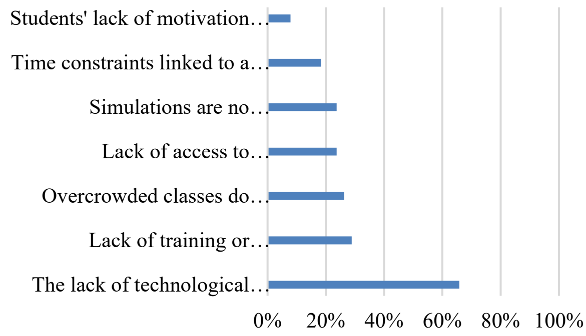

Figure 11. Barriers to the integration of simulations in teaching

Based on the data provided in Figure 11 concerning the barriers to the integration of Simulations in teaching practice, most of the physics teachers indicated that the lack of technological equipment in the school (65.8%) is the main obstacle that curbs the use of simulations, Also, (28.9%) of teachers declared that the lack of training or familiarity with the use of simulations is the primary concern. Others (26.3%) attribute this to Overcrowded classes that do not encourage the use of simulations. Additionally (23.7%) agreed that simulations are used additionally, and could not be as replacement for real experience and with the same percentage 23.7% declared that there is a Lack of access to simulations adapted to energy-related chapters. Other teachers stated that one of the obstacles that do not help to use simulations is the time allotted to the completion of the syllabus (18.4%), whereas few respondents with a percentage of 7.9% blamed lack of motivation on the part of students for simulation-based learning to be the major cause.

4. DISCUSSION AND IMPLICATIONS

The data obtained from the present study reveals that most teachers do not regularly conduct hands-on textbook experiments, with only a few performing these activities frequently. In terms of simulations, 63.2% of teachers incorporate them into their physics classes, while 36.8%

do not. When analyzing these data in accordance with teachers who use simulations for teaching energy chapters, the results showed that 44.1% of participants (n=30) declared using simulations to explain courses related to energy, whereas 55.9% of teachers (n=38) do not. These findings reflect a notable variance in the use of both hands-on experiments and simulations. The infrequent use of hands-on experiments aligns with studies that confirm the existence of technical, pedagogical, and ethical constraints. Similarly, the existence of epistemological constraints related to the nature of the subject and teaching practices has been highlighted which explains why many teachers do not incorporate simulations into their teaching of energy topics [14].

In the current study, Moroccan secondary school teachers frequently use interactive simulations to teach various energy concepts. "The mechanical energy of a solid" is the most commonly taught course using simulations, followed by course of "Energy Study" and "Work and Kinetic Energy". The findings of our research indicate that the majority of teachers resort to an investigative approach when integrating interactive simulations into their classroom practices. This approach is consistent with the principles of inquiry-based learning, which is to engage students in active learning and improve their conceptual perception by triggering a range of cognitive activities, to eventually formulate evidence-based explanations and reach conclusions [14]. This finding aligns with research showing that simulation-based learning environments provide students with more effective learning context [19].

Over half of the teachers (53.3%) reported using simulations as a complementary tool rather than a replacement for hands-on experiments, while 30% used them as an alternative to traditional hands-on laboratory experiences, and 16.7% used them as a complete substitute. These results align with previous research on comparative studies of traditional labs and virtual environments which noted that virtual environments should not be viewed as a total replacement for hands-on experiences, the latter appear to be essential for developing practical skills and fostering a deeper understanding of scientific concepts [20].

93.3% of the teachers felt they successfully achieved their pedagogical objectives with these simulations. This result aligns with a previous finding that teachers play a crucial role in aligning computer simulations with curricular objectives and student needs [15].

The results reveal that the majority of teachers strongly advocate the fact that the use simulations significantly enhance students' conceptual understanding of energy-related aspects, consistent with a study by Widiyatmoko, which revealed that using simulations allows learners to experimentally understand challenging concepts in science education [21]. Teachers noted that simulations help keep students engaged and interested in learning, similar to [22] who demonstrated a clear improvement in the student motivation levels via Interactive Learning Tools.

Additionally, they observed that simulations make learning more memorable and understandable and contribute to improve students results. Consistent with the findings of [23] this research highlights a significant correlation between the use of simulations for learning energy concepts which implies a remarkable improvement in students' performance and understanding. Teachers also reported that simulations reduce difficulties and misconceptions. Based on the research and discussion [14], it can be concluded that the use of simulations in a cooperative learning model is effective in minimizing students' misconceptions about the concepts of momentum and impulse.

Furthermore, most teachers agreed that simulations facilitate the visualization of energy-related phenomena. This finding is consistent with the study which shows that interactive simulations, such as PhET Simulations, help prospective teachers understand complex scientific concepts through visualization and direct interaction [15].

Comparing student engagement in the simulation-based and hands-on lab approaches revealed some interesting progression. The simulation-based instructional approach in the lab showed significantly higher average engagement, indicating that students were consistently engaged in these activities comparing to hands-on teaching method. This is consistent with research showing [4] that incorporating simulations into the instructional process, especially for abstract concepts such as energy, can promote active learning and keep students interested and engaged in learning energy concepts. These findings imply that the literature affirming the various benefits of simulations in science education have been confirmed

More interestingly, through the current study, we have been able to identify several main barriers to the incorporation of simulations in the teaching practices in Morocco, despite the ongoing efforts to incorporate computer-assisted instruction (CAI) as a supplementary teaching tool [24]. Teachers primarily highlighted the lack of technological equipment in schools, a finding consistent with [25] which emphasized the insufficiency of technological tools as a major constraint. Another significant obstacle is the lack of training or familiarity with simulations. A previous research findings reveal a lack of trust among Moroccan secondary school science teachers in the benefits of using technology in the classroom, resulting in a less creative attitude towards integration [26].

Overcrowded classes further complicate the use of interactive simulations, reflecting challenges noted by [27] regarding class size and technology use. Additionally, teachers pointed out the lack of access to simulations specifically adapted to energy-related chapters and noted that simulations are not a replacement for real experience. Reflecting on the findings from the study of Zacharia ZC [18]. Time constraints due to curriculum requirements were also mentioned, similar to a study on the limited classroom time for new technologies [28], this is due to the overloaded curriculum, as noted by secondary physical science teachers of Settat in Morocco [29]. To effectively implement simulations in education, the Ministry of Education should take several key steps. First, it is essential to equip school laboratories with the necessary computer hardware, software that align with the curriculum, and interactive simulation tools to empower teachers in enhancing student's conceptual understanding of energy-related concepts and skills while promoting the incorporation of simulations in teaching science. Second, ongoing remote training should be provided to science teachers to enhance their competencies, particularly emphasizing the utilization of ICT [30] and the implementation of online simulations, which are freely downloadable and usable in the classroom, such as PhET Simulations [16]. Training programs for pre-service teachers at regional education and training centers should emphasize the effective use of educational software, raising awareness of the value of simulations in the educational process [28].

5. CONCLUSIONS

The results of this study highlight the potential of incorporation simulations in improving students' conceptual understanding of energy-related aspects in the Moroccan secondary education. The responses gathered from Moroccan physics teachers regarding their use of interactive simulations indicate that the integration of simulations for teaching energy concepts varies widely among teachers. Even though this integration varies, the fact that many teachers use simulations demonstrates their openness to innovative technology. The findings reveal that simulations are generally appreciated for their ability to enhance student engagement and understanding. However, the primary obstacles to their effective use include a lack of technological equipment, insufficient training, and overcrowded classes. Despite these challenges, simulations are valued for their capacity to visualize complex concepts, reduce misconceptions, and improve student outcomes.

It would be beneficial to prioritize collaboration between Moroccan physics teachers and engineers in future research to develop simulations closely aligned with the Moroccan curriculum, particularly for energy lessons. This collaboration can increase the educational relevance and technical effectiveness of simulation while addressing infrastructure challenges, particularly in rural areas, to ensure equitable access. By emphasizing co-design and targeted professional development programs, educators and engineers can work together to identify best practices that will enable teachers to effectively integrate simulation into Moroccan classrooms.

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