The Perception of The Combination of Simulations and Laboratory Experiments by Moroccan Students

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Abstract. All over the world, secondary school students are losing interest in the physical sciences. The causes of this problem are diverse. To increase the motivation of learners, pedagogues recommend the integration of practical work in an effective way in the teaching process of experimental disciplines such as physical sciences. However, this work does not fill the gap between theory and practice. Simulation is of great interest in electricity, as it allows for the simplification of the real systems under study. Also, simulation can serve as a link between theoretical concepts and laboratory work. In this paper, we have proposed an approach based on the combination of simulation (virtual experiment) and laboratory work (real experiment) to teach electrical concepts. This approach is used to teach concepts related to capacitor operations. The proposed simulation allows students to change the parameters of the experiment and explore the phenomenon of capacitor charging. To measure the degree of user satisfaction with this approach, a questionnaire was administered to eighty students from a randomly selected high school. The results obtained show a favorable perception among the students of the positive effects of the combination of virtual and real experiences of electrical phenomena in the acquisition of electrical concepts.

Keywords: Physics, Simulation, Laboratory work, Electrical concepts, Capacitor charging phenomenon, Motivation, PSPICE simulator

1 Introduction

Skills related to the experimental method and critical thinking are paramount to effective teaching of physics [1]. With technological advances, there are new options for introducing these skills using simulators [2]. Certainly, students in the digital age are growing up with electronic devices and can navigate the virtual world. Hands-on activities can be a novelty compared to simulations [3]. Moreover, several research studies show that the use of simulations offers interesting opportunities to exercise higher order skills such as reflective thinking, abstraction, and advanced problem-solving skills [4]. In addition, recent research results show that hands-on work and simulations support students' learning of electrical circuits in a similar way [5]. Other studies indicate that the combination of computer simulation and traditional teaching has a positive effect on the teaching of physics and especially electricity [6], [7].

In this article, we propose an approach based on the combination of virtual experiments using simulation and real experiments using laboratory work. This approach aims at making the learning of electrical concepts more sustainable by linking the theoretical and practical knowledge of the learners. The simulation part of this approach gives learners the opportunity to be autonomous and free in their investigation and construction of scientific knowledge. Moreover, the simulations overcome the weak points of laboratory work: Learners are strictly guided, the fragility of the laboratory equipment, and the risks of mishandling this equipment. Therefore, the added value of our approach lies in the fact that real and virtual experiments are complementary and allow to reach the finalities of the experimental method based on the formulation of hypotheses, proposal of experiments and analysis of results. To achieve the objective of this research, we simulated the phenomenon of capacitor charging via the PSPICE simulator. The choice of this phenomenon is not arbitrary. This phenomenon is quite complex and difficult to assimilate by most high school students. The result of the simulation is followed by the real realization of the experiment using the laboratory equipment. To measure the degree of user satisfaction with this approach, a questionnaire was administered to eighty students. The main question of this research is: "What impact would the use of the approach based on the combination of simulation and laboratory work have on the acquisition of concepts in electricity?

The rest of this paper is organized as follows: the next section presents the theoretical framework in which this work is embedded. Section 3 is dedicated to the methodology of our research. Section 4 is dedicated to the presentation of the scenario of our approach based on the combination of virtual and real experiments. In section 5, we present the results of the questionnaire which aims at measuring the degree of satisfaction of our approach. The last section concludes the paper.

2 Theoretical framework

2.1 The benefits of the inquiry-based educational approach in sciences

Many countries want to increase enrolment in science courses to meet an expected demand for more scientists [1]. Learners around the world are losing interest in science [8]-[10]. The causes of this problem are diverse [11]. The abstract nature of some of the concepts taught is responsible for the lack of motivation of students towards science education [12]. Indeed, one of the most important factors that negatively influence students' attitudes towards science is the curriculum, the syllabus, and the professional practices of teachers [13]. Thus, educationalists emphasize the importance of teaching methods in improving the learning of experimental sciences and especially the learning of electricity [14]. Investigative learning places learners at the center of the learning process. They act as scientists and discover the phenomena studied by applying the experimental method based on generating hypotheses, designing experiments and interpreting results [15]. Indeed, inquiry-based learning is an approach that enhances science education by engaging students in real-life investigations. This pedagogical approach increases students’ motivation and prepares them to become active constructors of their own knowledge [16]. The inquiry-based approach is recommended by several researchers [5]-[7], [17]. However, this approach is little used in physical science classes and is often used in an ineffective way. This is due to several factors, such as the problem of using scientific materials that allow students to conduct investigations in an independent manner [18], the difficulty of incorporating abstract concepts into the investigation [16], the difficulty of achieving the actual objectives of the laboratory work [18] and the absence of cognitive bridges between theoretical and practical knowledge [19]. Also, improving students' critical thinking skills is among the most important objectives of science education [20]. However, physics teachers spend more time communicating information in class than doing experimental activities [21]. The teaching of these sciences, which is intended to be experimental, is in most cases theoretical without making strong links between theory and practice [22]. According to an exploratory study, most of these teachers carry out less than 50% of the experiments programmed in the textbook [23]. According to the same research, the lack of scientific equipment needed to carry out practical work is the source of this problem. To overcome this problem, computer simulation can replace some of the real experiments to make the learning of electricity concepts more interactive [24]. Also, simulation helps students bridge the gap between theory and reality, in the case of electrical circuits. It is a source of constructive feedback, helping students to identify and correct their misconceptions [25].

2.2 The added value of simulation in the educational context

Simulation is an explanatory means to define a system, an analysis vector to determine results, a design evaluator to analyze and evaluate proposed solutions [26]. In scientific disciplines, the computer was used very early because of the computational capabilities it offered. This speed provides a new tool for testing working hypotheses [7]. By simulating the results of a theory, one can quickly assess its validity and make much faster progress in the process of theory development [27]. This approach consists of making progress in the understanding of a real phenomenon by proposing a numerical model that can be compared and evaluated with the results of laboratory work [18]. Moreover, simulation allows the real systems studied to be simplified [28]. It presents itself as a "unique" didactic tool to overcome the problems caused by experiments that require long, dangerous, or expensive manipulations [18]. In the field of education, simulation allows virtual experiments to be carried out, giving students the opportunity to interact with the simulation software with total freedom, which is not always possible in laboratory work [29]. Also, simulations can be used as a complementary tool to the laboratory. Indeed, the combination of virtual experiments (via the simulation) and real experiments (via the laboratory equipment) saves time by reducing the duration of the laboratory session [30].

2.3 Common point and differences between simulations and laboratory experiments

Several researchers discuss the similarities and differences between real (using laboratory equipment) and virtual (using simulation software) experiments [31], [32]. Gilbert and Troitzsch state that simulation questions the model and not the phenomenon itself [33]. However, the material aspect, which is an important element for the external validation of experiments, is absent in simulation [34]. Certainly, the distinction between real and virtual experience must be based on the difference between internal and external validity. When formulating a hypothesis about a physical phenomenon, the internal validity of the virtual experiment (simulation) is simply the first step. The second step is to compare the internal results of the simulation with the external results of the experiments. The external validity of the experimental results is crucial to confirm or reject the original hypothesis. Thus, Winsberg [35] states that despite the differences between real and virtual experiments can make inferences about the world. Robin Millar and colleagues [36] point out that the discrepancy between teachers' and learners' goals influences the effectiveness of experimental activities. In principle, teachers' goals are inspired by the curriculum. After deciding on these objectives, the teacher designs the practical task. When this task is implemented, the teacher is focused on the process of investigation, while the learners are more concerned with giving a "right answer". To address this problem, physical science teachers are encouraged to promote autonomy and empower the learner in the experimentation phase [37]. However, poor choices by learners during the experimental phase can lead to multiple dangers. Certainly, the integration of simulation in the teaching of physical sciences can avoid such problems. Moreover, simulation can be more beneficial than laboratory experiments when unobservable or difficult-to-observe phenomena are addressed [18].

In short, several studies indicate that combining simulation with experiment-based teaching can have a beneficial effect on the learning process [5]. However, this requires a reform of pedagogical approaches to take advantage of the benefits of simulation in an optimal way. Furthermore, the integration of simulation into physical science teaching attracts the attention of students [38]. Students, by succeeding in their own simulations, acquire not only knowledge about the phenomenon represented by the simulation but also additional motivation.

3 Methodology

3.1 General context

Our research is intended for Moroccan high school students in the final year of the scientific section. To achieve the objectives of this research, a questionnaire was administered to eighty students at the public high school Abou Bakr Essediq. These students used the simulation and laboratory experiments in the teaching/learning process of electricity concepts for 3 months. The implementation of the study lasted 24 hours and was spread over 12 weeks (2 hours per week) in the multimedia (ICT) room of Abou Bakr Essediq High School.

3.2 Participants

The study population consisted of 212 secondary school students in an urban high school in Tetouan (Morocco), of whom 80 (37.7%) participated in the study. The high school was selected in a random way. Also, two classes were randomly selected to serve as the sample for the present study. The students of these two classes used the PSPICE simulation software (virtual experiments) in the teaching/learning process of electricity concepts before moving on to laboratory experiments (real experiments).

3.3 Instruments and procedures

The questionnaire aims at measuring the satisfaction of the students who benefited from the teaching based on the combination of virtual experiments and real experiments of the capacitor charging phenomenon. The virtual experiments were carried out by the PSPICE simulation software. The combination of these two types of experiments aims at bridging the gap between the theoretical and practical knowledge of the learners. The questionnaire is organized around four questions that allow the students to give their opinions about this new approach. The questionnaire is individual. It takes place in the Abou Bakr Eddedik high school, after the session of carrying out the virtual experiment of the capacitor charging phenomenon.

3.4 Data analysis

The data of our research was constituted from an individual questionnaire allowing Moroccan high school students to express their opinions concerning the effect of the combination of virtual and real experiments on the acquisition of electrical concepts. The questionnaire addresses the following issues:

- The PSPICE simulator is easy to use.
- The PSPICE simulator promotes autonomy.
- Simulation is an appropriate tool for the acquisition of the capacitor charging phenomenon.
- The combination of PSPICE simulator and laboratory work makes it easier to learn electrical phenomena.

These questions were developed based on the literature review [18], [21], [29], [30], [39], [40] and on open interviews with physical science teachers about improving the academic performance of Moroccan high school students in physics.
The answers to the questions in our questionnaire are of the 4-point Lickert scale type ("strongly agree", "slightly agree", "slightly disagree" and "strongly disagree").
After the collection of the completed questionnaires, the data was coded and compiled in an Excel database. The collection of data required the authorization of the headmaster of the Abou Bakr Essediq high school as well as the regional directorate of the Ministry of Education in Tetouan. The teachers and students interviewed were informed of the objectives and the course of the present research.

3.5 Example of simulation: Capacitor charging phenomenon

The set-up (see the following figure) consists of a resistor (R = 10KΩ), a capacitor (C=10 nF) and a DC voltage source (6 V). To calculate the voltage across the source and the capacitor, two voltmeters are placed.

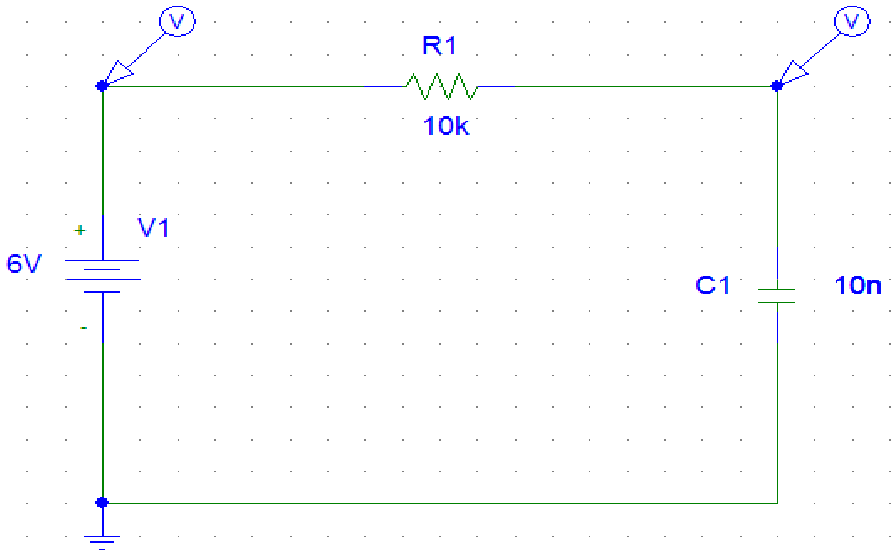

Fig. 1. Diagram of the capacitor charging phenomenon

The green curve is the voltage across the voltage source and the red curve is the voltage across the capacitor (see Figure 2).

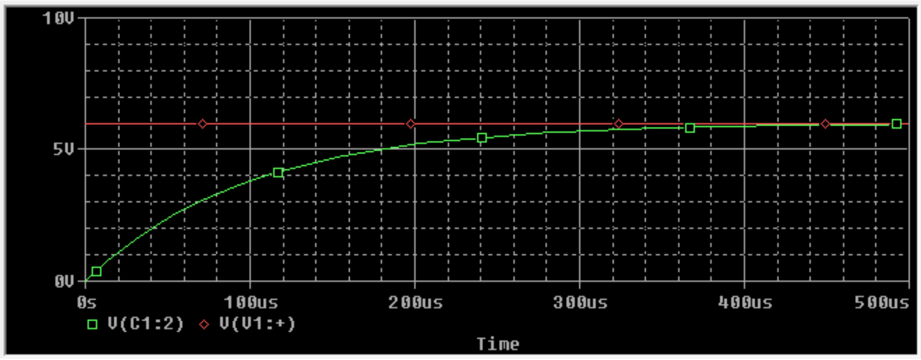

Fig. 2. Result of the simulation

4 Scenario for combining simulations with laboratory work

The cornerstone of this article is based on the scenario shown in Figure 3. At the beginning of the session, the teacher orients the scientific debate in the classroom towards the pedagogical objective to be achieved. He facilitates this debate to detect a scientific problem appropriate to the curriculum to be taught. Once the scientific problem is carefully identified, the teacher invites his students to propose working hypotheses (provisional solutions to the problem to be solved). Then, the teacher encourages the students to propose and then carry out the simulation (virtual experiment) using the PSPICE simulator. In case the results of the simulation allow to solve the problem detected at the beginning of the session, the teacher invites the students to carry out the same experiment but this time with the real scientific material of the laboratory (real experiment). In short, the approach used in this work is based on this scenario that combines real and virtual experiments in the acquisition of concepts related to the phenomenon of capacitor charging.

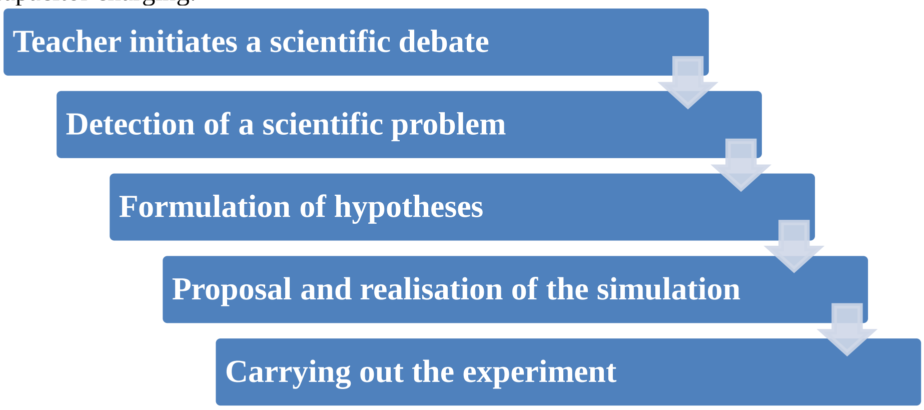

Fig. 3. Scenario of the combination of virtual and real experience

5 Results

The objective of the simulation of the capacitor charging phenomenon is to facilitate the cognitive task of Moroccan high school students in the process of acquiring concepts in electricity. It also aims at providing more freedom to the learners during their learning process to establish cognitive bridges between theoretical and practical knowledge. To measure the degree of user satisfaction with our approach based on the combination of virtual and real experiences, the following axes were proposed:

- The PSPICE simulator is easy to use
- The PSPICE simulator promotes autonomy
- The simulation is a suitable tool for the acquisition of the capacitor charging phenomenon
- The combination of PSPICE simulator and laboratory work makes it easier to learn electrical phenomena

5.1 The PSPICE simulator is easy to operate

The choice of the PSPICE simulator is not arbitrary. It is recommended by many educators for teaching electricity. However, it is interesting to check whether this tool is appropriate for Moroccan high school students. For this reason, we have programmed these five questions: The PSPICE simulator is easy to operate :

- At the level of installation
- At the level insertion of electrical components
- At the level of drawing the diagrams
- At the level of simulation parameterization
- At the level of visualisation of the results

The following figure summarizes the results of the Moroccan high school students' answers.

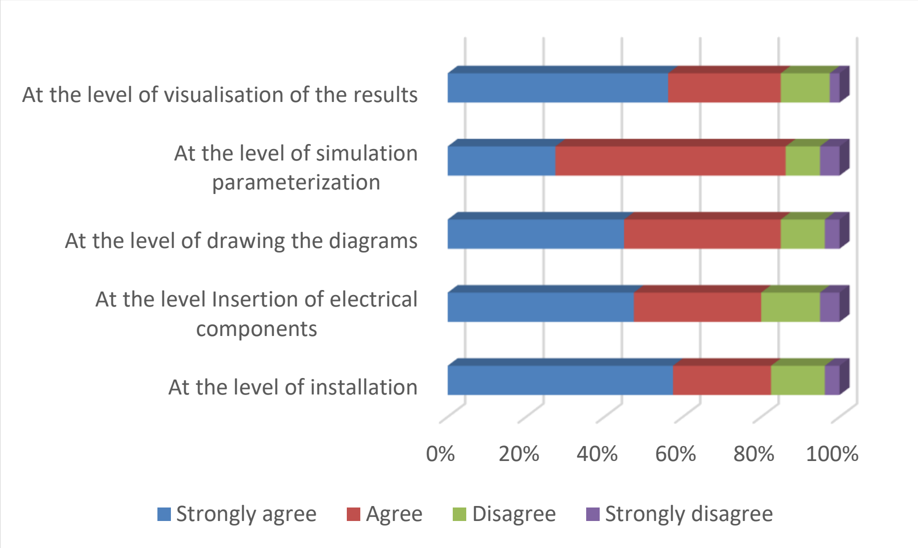

Fig. 4. The PSPICE simulator is easy to operate

The results show that the majority of students (more than 80%) find that PSPICE is easy to exploit in terms of installation, at the level of the insertion of electrical components, in terms of drawing of the diagrams, in terms of configuration of the simulation and at the level of visualization of the results of the simulations.

5.2 The PSPICE simulator promotes autonomy

To measure the degree of satisfaction of students at the level of self -regulation of assimilated knowledge and at the level of autonomy, we have programmed these three questions: The PSPICE simulator promotes autonomy:

- In terms of extracurricular activities
- In terms of the investigation approach
- In terms of knowledge self -regulation

The following figure summarizes the results of the Moroccan high school students' answers.

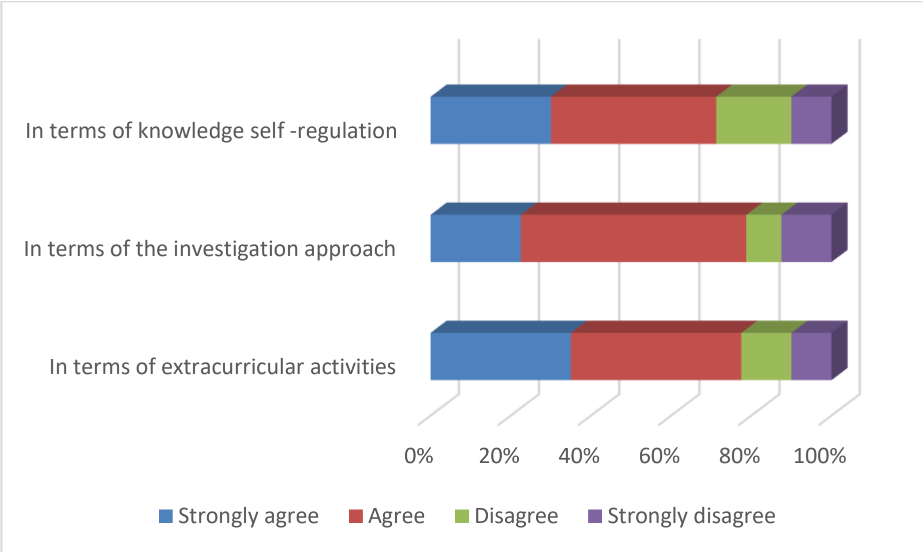

Fig. 5. The PSPICE simulator promotes autonomy

The results show that more than 65% of the students find that PSPICE can be used as a tool for self-regulation of knowledge and learner autonomy in class and in extracurricular activities.

5.3 Simulation is an appropriate tool for learning about capacitor charging

To measure the degree of satisfaction of the students in using the PSPICE simulator to study the phenomenon of capacitor charging, we programmed the following question: Is simulation an appropriate tool for the acquisition of the capacitor charging phenomenon?

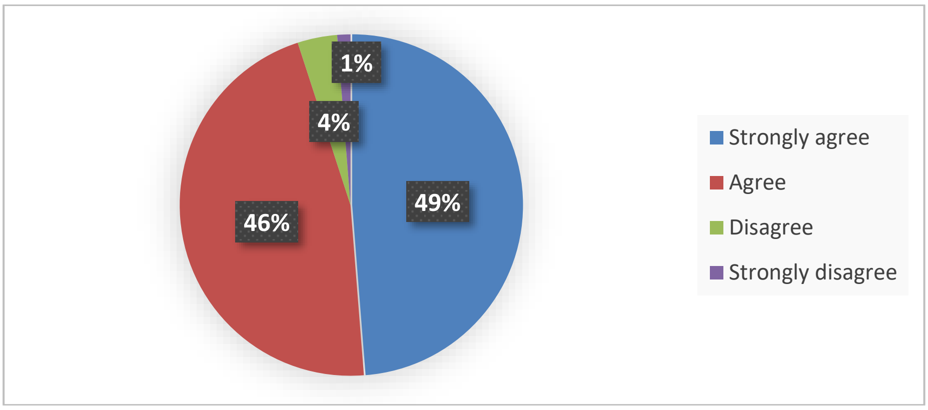

Fig. 6. Simulation is an appropriate tool for learning about capacitor charging

According to the same questionnaire, 95% of the students surveyed found that the integration of PSPICE helped to assimilate the concepts of the capacitor charging phenomenon (see Figure 6).

5.4 The combination of the PSPICE simulator and the laboratory work makes it easier to learn electrical phenomena

To measure the students' perception of the use of our approach to learn electrical concepts, we programmed the following question: The combination of real and virtual experiments makes it easier to learn electrical phenomena.

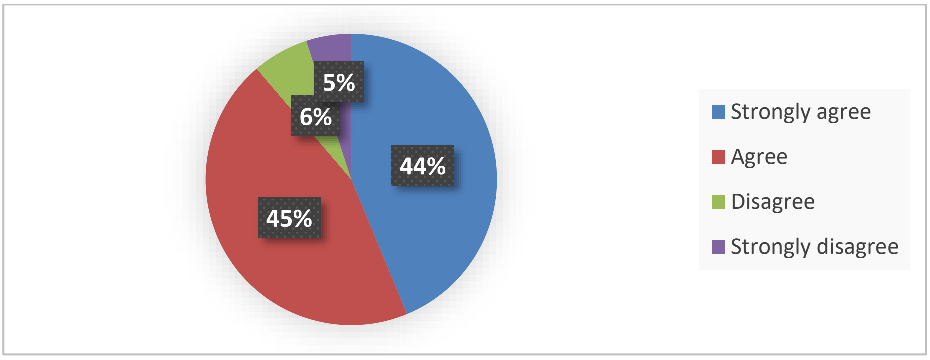

Fig. 7. Simulation is an appropriate tool for learning about capacitor charging

In the last question of our questionnaire, the students' answers show that there is a positive perception of the combination of the PSPICE simulator and the laboratory work. Moreover, they consider that this combination makes it easier to learn about electrical phenomena (see Figure 7).

5.5 Discussion

The results of the questionnaire show that the PSPICE simulator is easy to operate for most of the students surveyed and most of these students think that PSPICE promotes autonomy in them. Also, 95% of the students surveyed felt that the simulation was able to reduce some of the difficulties related to the acquisition of the concepts of the capacitor charging phenomenon. Furthermore, the students interviewed expressed a positive perception of our approach based on the combination of real and virtual experiments. This is in harmony with the results of other research conducted in at least similar contexts [21], [25], [29], [30], [40]. Furthermore, during the facilitation and supervision of the workshops that incorporate our approach, we found that the students were remarkably motivated and that our approach enabled these learners to construct their own knowledge by modifying the parameters of the simulation software and immediately visualizing the results of their modifications. However, the results obtained in this research are based on declarative data. The students interviewed express their opinions about the effect of the integration of our approach on the acquisition of electrical concepts. These opinions may not reflect reality. In this situation, it will be important to consolidate the results obtained through research that aims to study the behavior of Moroccan high school students in a more profound way when combining real and virtual experiences.

In short, virtual, and real experiences can be complementary in the learning process of physical concepts. Indeed, it will be beneficial to apply the experimental method using simulation before moving on to real experiments. In this way, learners can be given more freedom in the investigation process. This represents an opportunity for learners to build cognitive bridges between theoretical and practical knowledge. As a result, learners are motivated, active, and responsible for their learning.

6 Conclusion

Laboratory experiments and computer simulations can achieve similar goals, such as increasing students' interest in science and raising their understanding of electrical concepts. While the learners are guided in the laboratory work because of several constraints, on the contrary, they are totally free when using the simulation software. This represents an opportunity for them to be free in the experimental method and especially in the verification of hypotheses with the help of virtual experiments. On the other hand, the lack of experimental activities is the main cause of the introduction of misrepresentations in learners [41]. The latter is due to the lack of physical facilities in the institutions [23]. In this situation, simulations will be an alternative to perform virtually inaccessible experiments. Also, the results obtained in this study show that high school students are motivated to integrate our approach based on the combination of real and virtual experiments in the teaching/learning process of electricity concepts and they consider that the same approach was able to reduce some of the difficulties in acquiring the concepts related to the capacitor charging phenomenon. Despite the various advantages of simulation, it cannot replace experiments. Moreover, it can lead to erroneous behavior associated with the physical model used, which aims to simplify the phenomenon studied. To avoid confusing the learner, the model should be neither too small nor too complex [42]. Simulations should be introduced at the right time in the course, using the right pedagogical strategy and with very precise pedagogical objectives [43]. However, there is a risk that users of simulators may confuse a real phenomenon with its representation in simulation. To avoid this risk, some researchers insist that it is necessary to clearly separate reality, simulation, and theory [43].

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