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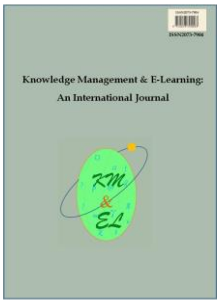
Adil Hamamous
Nadia Benjelloun
Sidi Mohamed Ben Abdellah University, Fez, Morocco



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Impact of using computer-assisted experimentation on learning physical sciences in secondary schools in Morocco

Adil Hamamous*

Laboratory of Computer Science, Signals, Automation, and Cognitivism
Faculty of Sciences Dhar El Mahraz
Sidi Mohamed Ben Abdellah University, Fez, Morocco
E-mail: adil.hamamous@usmba.ac.ma

Nadia Benjelloun

Laboratory of Computer Science, Signals, Automation, and Cognitivism
Faculty of Sciences Dhar El Mahraz
Sidi Mohamed Ben Abdellah University, Fez, Morocco
E-mail: nadia.benjelloun@usmba.ac.ma

*Corresponding author

Abstract: This research is part of the integration of information and communication technologies (ICT) in the Moroccan education system, our objective being to evaluate the use of computer-assisted experimentation (CAEx) in learning to encourage the authorities of the Ministry of National Education, Vocational Training and Sports to adopt the CAEx program in the teaching and learning of physics so that it becomes compulsory for all high schools. To evaluate the impact of using CAEx in the study of free oscillations of an RLC circuit (a linear circuit containing an electrical resistor, an inductor, and a capacitor). A study was conducted with 40 Moroccan students in the second year of the scientific baccalaureate option life and earth sciences at the high school Abdellah Laroui in the city of Fez, as this work aims to highlight the effect of the use of CAEx on the learning of students. Using the methodology of pre-test and post-test with an experimental group (20 students) and a control group (20 students). The results of both groups are analyzed with IBM SPSS 21 statistical analysis software the results obtained from the post-test show that the average of the tests addressed to both control and experimental groups has a significant difference. In addition, non-directive and directive interviews were conducted with the students of the experimental group. Indeed, the content of the grid of open and closed questions was elaborated in agreement with the teachers of physical sciences of the high school Abdellah Laroui, concerning the use of CAEx in learning and to know the degree of satisfaction of the integration of CAEx in the study of free oscillations in an RLC circuit. In addition, the data were processed by Sphinx v5 software. This study showed that CAEx integration had a positive effect on student learning. It can be said that CAEx plays an important role in the grasp and assimilation of scientific concepts, and it represents a solution to make the student more attentive and serious. Computer Aided Instruction can develop a spirit of initiative in the learner.

Keywords: Education; Oscillations; Physical sciences; e-Learning; Information and communication technology; CAEx

Biographical notes: Adil Hamamous pursued his university studies at the Faculty of Sciences Dhar El Mehraz of Fez, where he obtained his bachelor's degree and his postgraduate diploma in solid state physics, with a specialization in the physics of materials for the environment and nanostructures. In 2007, he was recruited by the Ministry of Education as a teacher at the Secondary School of Physical Sciences. His research focuses on the integration of information and communication technologies (ICT) in education. He started his current doctoral research entitled "Relations between simulations, CAEx and cognitivism in physical sciences" at the University of Sidi Mohamed Ben Abdellah, Faculty of Science, Dhar El Mahraz, Fez, Morocco. Doctoral training in Didactics of Sciences and Pedagogical Engineering, Laboratory of Computer Science, Signals, Automation, and Cognitivism.

Nadia Benjelloun was born in Fez, Morocco. After graduate studies in physics at the University of Strasbourg and obtaining her Ph.D. in solid state physics at the Vrïje Universiteit Brussel in 1990, she joined 1992 the Physics Department of the Dhar El Mahraz Faculty of Sciences of Sidi Mohamed Ben Abdellah University of Fez. In 1995, she created the Physics Didactic Group there. In 2003, she created in collaboration with the research group in didactics of mathematics, the Training and Research Unit in Didactics of Mathematics and Physical Sciences, then in 2008, the Doctoral Training in Didactics of Sciences and Pedagogical Engineering. Her research focuses primarily on misconceptions and misrepresentations among pupils and university students in the fields of mechanics, optics, electricity, etc. as well as on the development of teaching scenarios to overcome the difficulties identified among learners. She then focuses her research on the experimentation and evaluation of the integration of information and communication technologies in teaching and the evaluation of the impact of these tools on learning. More recently, she is interested in the study and evaluation of the impact of e-learning and artificial intelligence on teaching and learning. Pr. Nadia Benjelloun has supervised several doctoral theses and published several articles, in solid-state physics, didactics of physics, and educational engineering.

1. Introduction

Morocco's Ministry of National Education has been working to integrate information and communication technologies (ICT) into the education system since the early 1990s, as they provide innovative means not only for the transmission of knowledge but also for the exploration of training strategies that promote skill development (Perreault, 2003). Information and Communication Technology (ICT) in education is a field of educational technology devoted to research and pedagogical applications that specifically relate to the teaching-learning approaches, processes, and techniques involved in pedagogical actions that integrate the use of digital tools (Bangou, 2006). ICT provides an opportunity to rethink and delocalize, in space and time, exchanges between teachers and students, and thus promote new avenues for learning or training activities (Depover et al., 2007). Appropriate technological tools increase the desirability and searchability of information (Hosseini et al., 2021). Furthermore, introducing ICT tools into lecture delivery assists teachers in adopting creative teaching approaches while also increasing learners' curiosity and understanding, resulting in increased learning capacity and personal growth (Al Shuaili et al., 2020), according to Keržič et al. (2021) the use of ICT for educational purposes independent the age of teachers. In the past, many researchers, including Nurliani et al. (2021) noted that ICT is capable of expanding students' knowledge of physics. Advanced ICT instruments such as gamification, simulation, and problem-solving and simulating practices become vital and effective in assisting lectures (Erdmann & Torres Marín, 2019). The beneficial contributions of ICT integration are numerous, namely accessibility, flexibility, and increased interaction and exchange between the various stakeholders in the field of education (Karsenti, 2003; Nafidi et al., 2015). In addition, ICT can support active learning and foster the development of several cross-cutting skills that make the learner capable of producing, exploiting, processing, organizing, and sharing information (Biaz et al., 2009). ICT plays an important role in reducing the frustration of students with learning disabilities who participate in experiential activities and may even improve their self-efficacy to some extent (Çoban et al., 2022; Ma et al., 2021). Because the integration of technology allows for the modification of human nature and cognition, ICT tools are frequently regarded as artificial organs in the core of human beings, alongside biological organs that allow humans to continue transforming the world while also transforming themselves (Sánchez-Sordo, 2019). In addition, Jeong and Kim (2022) show that the use of computer-aided mapping tools improves critical thinking skills. Using ICT, learners can be more motivated and achieve better results (Belkebir & Darhmaoui, 2018; Droui et al., 2013; Hu et al., 2021; Ouardaoui et al., 2012; Zakaria et al., 2014), and enable the learner to carry out experiments in the case of computer-assisted experimentation (Khazri et al., 2017).

The National Charter of Education and Training in Morocco (1999) specifies in lever 10, the objective of equal opportunities for access to information and communication and aims to alleviate the difficulties of teaching and training. Among the most promising means of teaching experimental sciences is certainly computer-assisted experimentation (CAEx), which is an important area of use of ICT in experimental sciences, interacting with a real experiment through an interface equipped with sensors and connected to a computer to collect data, represent and analyze different levels (Caron, 2007), CAEx refers to educational applications that use a computer system (computer, interface, sensors, and software) as a robot (Pellerin, 2016). Leonard (1990) noted that CAEx is the most appropriate category for practical work in science education. The equipment of CAEx in Moroccan high schools started in 2009 (Atibi, 2017). The study by El Ouargui et al. (2019) shows that nearly 60% of schools are equipped with CAEx equipment, but the number and availability of this tool remain insufficient. The student is thus placed in a real laboratory environment allowing him to design, plan, and carry out experiments in physics, electronics, and chemistry. CAEx also makes it possible to control the variables and the student will be able to visualize the data of his experiment in graphic form and carry out mathematical modeling on this basis (Lauzier, 2004). Thus, the CAEx consists of the same elements:

A sensor that measures the change of a physical quantity and generates an analog electrical signal whose value is proportional to the measured parameter, the electrical signal from the sensor is applied to an acquisition interface including an analog/digital converter, and the interface converts the analog signals into digital signals that it sends to the computer, a suitable software interface drives and allows you to process the measurements, including graphically (Gourja & Tridane, 2015). Physics teaching software can be used as laboratory tools during computer-assisted experimentation (CAEx) (Zakaria et al., 2014). CAEx also develops scientific and critical thinking skills, enhances student potential, and promotes student autonomy (Riopel & Nonnon, 2005).

The objective of our work is to study the effect of integrating CAEx on students' understanding and learning of free oscillations in an RLC circuit (a linear circuit containing an electrical resistor an inductor, and a capacitor) and the value of this study is reflected in the comparison of the traditional teaching method with CAEx in the acquisition of scientific concepts to improve student performance. The importance of this study is to push the Ministry of National Education and Vocational Training to adopt the CAEx program.

Information and communication technologies (ICT) have provided innovative tools (Tarman & Dev, 2018). Since the early 1970s, investigators have compared traditional teaching methods with those of CAEx in the acquisition of scientific concepts. Most of these studies show that the uses of CAEx are more effective than traditional teaching methods (Atibi, 2017). In this work, the use of CAEx is due to the observation of several learning difficulties during the teaching of the RLC circuit such as: visualizing the different oscillation regimes, knowing how to connect an oscilloscope to visualize the different voltages, highlighting the influence of R, L, and C on the oscillation phenomenon, knowing the role of the oscillation maintenance device, which consists of compensating for the energy dissipated by Joule effect in the RLC circuit.

On the other hand, those in charge of the education sector in Morocco are aware of the important role that the integration of CAEx can play in teaching and learning, for this reason, they have given important spaces to the integration of CAEx in the field of education in the different stages of the reform of the education system. There are two considerations were the choice of electricity as a domain to test the performance of the use of CAEx: First, in the physics curricula of the secondary cycle, electricity is the domain whose development is the most complete, it occupies an important time slot in the teaching of physical sciences in Moroccan secondary. Second, learning electricity presents a real challenge for learners throughout their schooling. However, the study results do not allow for general conclusions to be drawn for the following consideration: The total number of samples used in the study remains small compared to the total number of learners.

2. Materials and methods

To investigate the processes of using CAEx in the study of free oscillations in an RLC circuit, a mixed methodological approach was adopted, in which we combined quantitative and qualitative data in the same study coherently and harmoniously. The methodology adopted in this study revolves around the comparison of the responses of students in the control and experimental groups to the pre-test/post-test and the processing of the results of an interview survey. After obtaining formal authorization from the principal of my school in addition, we informed the participants of our research objectives.

2.1. Instruments

Our sample is composed of two groups among Moroccan learners in the qualifying secondary school of the second year of the scientific baccalaureate option life and earth sciences at the high school Abdellah Laroui in the city of Fez, who have an average age of 17 years, during the school year 2021-2022, using the school management system

“MASSAR”, we divided the samples into two homogeneous groups. We make sure that some criteria are similar to guarantee a fair comparison of the performances of the two groups, the two groups are approximately at the same cognitive level, and their school marks are close. Under the same teaching conditions as the official instructions are respected, both groups have the same pre-acquisition of electricity. The control group is composed of 20 students and the experimental group is also composed of 20 students. First, a pre-test (see Appendix II) was used with both groups to ensure equivalence and to assess the degree of mastery of the previous year’s pre-learning. This test consisted of five multiple-choice MCQs of two true or false choices and one exercise in the form of open-ended questions. This instrument was developed and piloted with 20 students, and its reliability was estimated using Cronbach’s alpha internal consistency coefficient. The reliability score was found to be 0.70 (see Table 1), indicating an acceptable reliability coefficient. Both groups were asked to answer the pre-test questions and the answers were presented in paper format.

Table 1
Reliability statistics (pre-test)

Cronbach’s alpha	Cronbach’s alpha based on standardized items	Number of elements
.704	.714	11

We acquired the CAEx knowledge through initial training in the education training center and continuous training for about ten hours with the education inspector. To evaluate the added value of CAEx during free oscillations in a series RLC circuit, we developed a post-test (see Appendix III) that was administered to both groups of students after they had experimented with CAEx with the experimental group using a datasheet in the optional program for one hour (see Appendix I), the CAEx system consists of the data acquisition and computer analysis systems. Nine fundamental elements make up this CAEx system: the computer, the voltage/current sensor, the GLX interface, the DATA STUDIO software, the adjustable DC voltage generator, the variable resistor, the variable capacitor, the variable inductance inductor, and the electrical wires (see Fig. 1).

The control group received the same part of the course of free oscillations in an RLC circuit in the conditions of teaching respecting the official instructions based on the classical pedagogical practice, the post-test is composed of three questions of two choices true or false, and two exercises of open questions which aims at the evaluation and the regulation of the basic knowledge which allows the students to continue their learning: discharge of a capacitor in an inductor, influence of pseudo-period damping, energy transfer between the capacitor and the inductor, graphical study in the case of low damping (negligible resistance) and maintenance of oscillations. This instrument was piloted with 20 students, and its reliability as measured by Cronbach’s alpha was satisfactory (Cronbach’s alpha = 0.72) (see Table 2). After completing the proposed learning activity, we invited both groups to answer the post-test questions in a paper-and-pencil format to compare their responses.

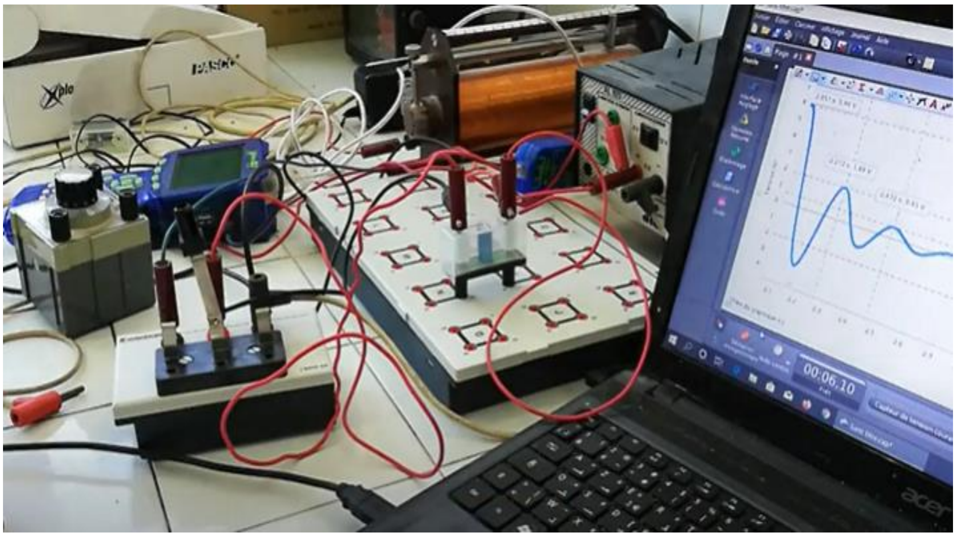

Fig. 1. Assembly of free oscillations in an RLC circuit with the CAEx

Table 2
Reliability statistics (pre-test)

Cronbach's alpha	Cronbach's alpha based on standardized items	Number of elements
.724	.738	9

The collected data were then analyzed with IBM SPSS Statistics 21 (statistical analysis software). A student's *t*-test was used to compare the groups of two independent samples, and an alpha level of .05 was used throughout the analysis of the results.

2.2. Interview

Our interview concerns all the students (N = 20) of the experimental group in the qualifying secondary school of the second year of the scientific baccalaureate option life and earth sciences in the high school Abdellah Laroui of the city of Fez. Non-directive and directive interviews were conducted with the students according to the protocol (see Appendix IV).

2.3. Data processing

First, the written transcript of the non-directive interview was made according to a grid keeping the main themes of the interview grid. The answers have been classified according to precise categories to be exclusive. They were induced, often, according to keywords. In the second step, the directional interview data were processed with the Sphinx v5 software. The different stages of this process are shown in Fig. 2.

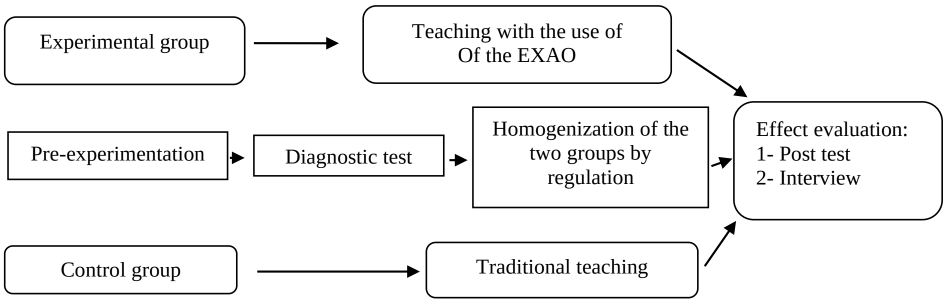

Fig. 2. Descriptive diagram of the experiment's approach

The aim is to get an idea of their appreciation and satisfaction with the integration of CAEx in the study of free oscillations in an RLC circuit.

3. Results

3.1. Pre-test results

The results of the pre-test for both groups are shown in Table 3.

Table 3
Descriptive statistics (pre-test)

	N	Minimum	Maximum	Mean	Standard Deviation	Variance
Control group	20	10.00	17.00	13.75	2.35919	5.566
Experimental group	20	9.00	18.00	14.05	2.32775	5.418

Analyzing these results, the pre-test mean of the students in the experimental group is Mean = 14.05, while that of the students in the control group is Mean = 13.75; the difference is about .3. We used the test of equality of variances of Levene's errors of two samples with a normal distribution (see Table 4, Levene's *p*-value is not significant). The null hypothesis is the difference between the means of students in the experimental and control groups is not significant.

Table 4
Test of equality of variances of Levene's errors

D	*df1*	*df2*	Sig.
.085	1	38	.772

The results of the comparison are presented in Table 5.

According to this table, the *p*-value of the ANCOVA test higher than the alpha level is chosen, a *p*-value of .851 does not imply the rejection of the null hypothesis; thus, we can estimate that there is no significant difference between the tested groups, this shows that both groups have the same level of skills, this result was predictable because both groups received the same course before the pre-test and allow us to validate our experimental model based on a pre-test and a post-test.

Table 5
ANCOVA test

Source	Sum of squares of type III	*df*	Average of squares	D	Sig.
Corrected model	.225	1	.225	.036	.851
Ordinate at the origin	9579.025	1	9579.025	1518.260	.000
Con and Exp groups	.225	1	.225	.036	.851
Error	239.750	38	6.309		
Total	9819.000	40			

3.2. Post-test results

The post-test results for both groups are presented in Table 6 below.

Table 6
Descriptive statistics (post-test)

	N	Minimum	Maximum	Mean	Standard Deviation	Variance
Control group	20	9.00	17.00	13.45	2.58488	6.682
Experimental group	20	12.00	18.00	15.40	1.93037	3.726

The results show that the mean of the students in the experimental group at the post-test is Mean = 15.40, while that of the students in the control group is Mean = 13.45; the difference is about 1.95. To check whether this difference is significant and to reject the null hypothesis that the educational device tested did not affect the students' results, the student's *t*-test was used to test the difference between the means of two independent samples with a normal distribution (see Table 7, the Shapiro-Wilk *p*-value is not significant).

Table 7
Normality tests

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistics	*df*	Sig.	Statistics	*df*	Sig.
Control group	.131	20	.2	.929	20	.146
Experimental group	.147	20	.2	.932	20	.170

The results of the comparison are presented in Table 8.

This table shows the results. the variances can be considered homogeneous; the *p*-value of Levene's test is $p = .153$, which is not significant. The *p*-value of the *t*-test is below the selected alpha level ($p < .05$); a *p*-value of 0.01 allows for rejecting the null hypothesis and thus admits that the integration of the CAEx in a situation of the study of free oscillations in an RLC circuit has certainly had a positive effect on the student's performance. This shows that the students in the experimental group are developing their understanding of visualizing the different oscillation regimes and visualizing the influence of the circuit resistance on the oscillation regimes.

Table 8
Independent sample test

	Levene's test for equality of variances		*t*-test for equality of means						
	F	Sig.	*t*	*df*	Sig. (2-tailed)	Mean difference	Std. Error Difference	95% confidence interval of the difference Lower	Upper
Equal variances assumed	2.125	0.153	-2.703	38	0.01	-1.95	0.72138	-3.41037	-0.48963
Equal variances not assumed			-2.703	35.165	0.011	-1.95	0.72138	-3.41424	-0.48576

According to the post-test results (see Appendix II) presented in Table 9, most of the responses of the students in the experimental group are correct answers to the questions (Q3 of MCQ, Q1 exercise 1, Q2-1 exercise 1, Q2-3 exercise 1, and Q1 exercise 2), while the case is different for the students in the control group. The observed remark is also the rate of correct answers of the experimental group for question Q3 of the MCQ which deals with the influence of L on the oscillation phenomenon (80.0%), the exercise 1 question Q1 which deals with the influence of R on the oscillation regimes (65.5%), Question Q2-1 of Exercise 1, which determines the value of the pseudo-period T of the electrical oscillations (75%), Question Q2-3 of Exercise 1, which consists of the role of the oscillation maintenance device (90%) and Question Q1 of Exercise 2, which allows knowing the energy diagrams (70%). For these questions, the response rates of the students in the experimental group were higher than those of the control group. This confirms that the use of CAEx allows for good assimilation and understanding of the course.

Table 9
Correct answers for control and experimental groups

	Q3 of MCQ	Q1 exercise 1	Q2-1 exercise 1	Q2-3 exercise 1	Q1 exercise 2
Control group	65.0%	55.0%	55.0%	75.0%	60.0%
Experimental group	80.0%	65.0%	75.0%	90.0%	70.0%

3.3. Interview

To get a fuller picture of the reality of this study, which aims to investigate the impact of the use of CAEx on the understanding of free oscillations in an RLC circuit in learners of the second year of the baccalaureate option Life and Earth sciences. A mixed methodological approach was chosen for this study, i.e., the combination of the quantitative research method with another qualitative research method based on the interview, this method considers the opinion of the student who has learned the course either through classical teaching practice or through CAEx.

- Did you encounter any difficulties when learning about free oscillations in an RLC circuit?
- What are the benefits of integrating CAEx into the learning process?
- What is the added value of using CAEx?

Some student responses:

- I have a problem visualizing the different regimes of RLC oscillations.
- I have difficulty highlighting the influence of R, L, and C on the phenomenon of RLC oscillations.
- With CAEx, we are more likely to modify to see the effect on the variables.
- CAEx encourages us to make experiments by ourselves.
- CAEx facilitates the development of teamwork skills.
- We can start over if we make a mistake.

The objective is to measure their satisfaction with the integration of CAEx in the study of free oscillations in an RLC circuit, after data processing by the protocol indicated in the methodology section, the students stated that they had a lot of difficulties with the following concepts: visualizing the different oscillation regimes, knowing how to connect an oscilloscope to visualize the different voltages, highlighting the influence of R, L, and C on the oscillation phenomenon, knowing the role of the oscillation maintenance device, which consists of compensating for the energy dissipated by the Joule effect in the RLC circuit, and the transfer of energy between the capacitor and the inductor. The CAEx environment in teaching makes students autonomous, active, and able to build their knowledge and work in groups and the CAEx helps the student to graph the interaction of the variables under study and to visualize. On the other hand, the students also confirm that thanks to the integration of CAEx in the classroom sessions, these difficulties have been overcome. In addition, in the analysis of the directive interview by the Sphinx v5 software (see Fig. 3).

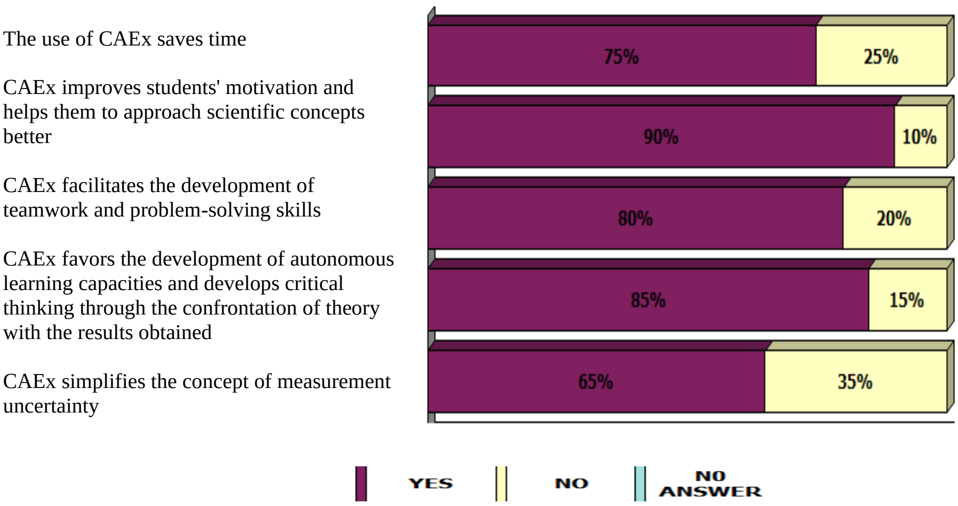

Fig. 3. Results of a directive interview

We emphasize that 75% of the students declare that the use of CAEx saves time. 90% of the students say that CAEx improves student motivation and helps to better approach scientific concepts. In addition, 80% of the students say that CAEx facilitates the development of teamwork and problem-solving skills. According to 85% of the students, CAEx helps develop independent learning skills and develops critical thinking by comparing theory with results. On the other hand, 65% of the students stated that CAEx simplifies the concept of measurement uncertainty.

4. Discussion

In this study, it appears that the students in the experimental group who used the CAEx were generally successful in setting up procedures that allowed them to answer questions more efficiently. The post-test responses confirm that these students also acquired skills concerning free oscillations of an RLC circuit. Such as, students become able to visualize the different oscillation regimes, know the influence of the circuit resistance on the oscillation regimes, deal with the charge and discharge of a capacitor in an inductor, know how to influence the pseudo-period on the damping, study the energy transfer between the capacitor and the coil easily, study graphically low damping (negligible resistance) and how to do the maintenance of RLC oscillations. The students interviewed agree that the facilities are numerous: CAEx allows us to start over if we make a mistake; an easy collection of data; the possibility of modifying the set-up to see the effect on the variables; allows us to see in real-time what is happening; facilitates the development of teamwork skills; CAEx helps the student to graph the interaction of the variables under study and to visualize; CAEx encourages us to do experiments on our own. Similarly, previous studies have confirmed that the use of CAEx in the classroom provides a measure of its contributions to the students and the assimilation of the concepts among the students (Gourja & Tridane, 2015). Yusuf and Afolabi (2010) reported that the performance of students using CAEx either individually or cooperatively was better.

It can be inferred that the integration of CAEx had a positive effect on students' learning. For example, the use of CAEx saves time by processing the data and drawing the curves which facilitates the teacher's work during the meeting, of course, to be able to finish the program in the desired time, on the other hand, to correct the students' representations and steer them in the right direction. In addition, CAEx processes the data and quickly transforms the algebraic values into numerical and graphical corresponding curves instantly. However, the use of CAEx in classrooms by teachers in their practical work is still very limited in Morocco, because of the lack of continuous training of teachers, the number of students in the classes is too high and the curriculum is overloaded which does not allow to perform experiments with students (El Bachari et al., 2010). In addition, there are also disadvantages to using CAEx as a tool, the student only manipulates manually and does not draw the graph himself (Atibi, 2017).

5. Conclusion

At the end of this study, the objective is to highlight the effect of the use of CAEx on students' learning. The statistical data collected from research among Moroccan learners in the second year of the baccalaureate option life and earth sciences at the high school Abdellah Laroui in the city of Fez, using the pre-test and post-test methodology with an experimental group and a control group showed that there was no significant difference between the two groups in the pre-test. In the post-test, after using the CAEx, there was a statistically significant difference between the experimental group and the control group, as the p-value of the student's t-test is lower than the selected alpha level ($p < .05$); a p-

value of .01 allows us to reject the null hypothesis and admit that the integration of the CAEx in a situation of the study of free oscillations in an RLC circuit had a positive impact on the student's performance. Indeed, the results obtained show that the successes of the students in the experimental group are higher than those of the control group. There are many advantages of using CAEx: CAEx saves time (75%), improves student motivation, helps to better approach scientific concepts (90%), facilitates the development of teamwork and problem-solving skills (80%), favors the development of independent learning skills, and develops critical thinking by confronting theory with results (85%) and simplifies the concept of measurement uncertainty (65%). The quantitative and qualitative analyses of the results confirmed that the pedagogical integration of CAEx had a positive effect on strengthening students' understanding.

6. Contributions

Our study may also encourage physical science teachers to use CAEx in their labs, as many of the students interviewed mentioned that the use of CAEx can significantly improve students' skills, certain indicators such as motivation and interaction between students compared to the conventional method. The results of this study may become the precursor of larger-scale research, with the aim of better understanding the opinion of teachers and students on the integration of CAEx in the school curriculum and may encourage the authorities of the Ministry of National Education, Vocational Training and Education to adopt the CAEx based program.

7. Limitations

This research has some limitations. 40 Moroccan secondary school students qualifying for the second year of the scientific baccalaureate option life and earth sciences in the high school of Fez, who have an average age of 18 years participated in this study which does not allow us to formulate general results due to the small number of samples, it would be advantageous to conduct similar research in the different discipline (life and earth sciences) with a large number of samples and this study concerns only the Moroccan context.

8. Future directions

The results of this study lead us to the conclusion that it can be a starting point for future research. In this research, we have emphasized the importance of continuing education for physical science teachers in the integration of CAEx into their professional practice. One research can target the training needs of students for optimal use of CAEx in their learning. Another interesting research is to do a similar study with other students from different countries with a larger sample size.

Author Statement

The authors declare that there is no conflict of interest.

ORCID

Adil Hamamous https://orcid.org/0000-0002-7628-7170

Nadia Benjelloun https://orcid.org/0000-0002-6837-3896

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Appendix I

Datasheet on the study of free oscillations in an RLC circuit by CAEx

Objectives

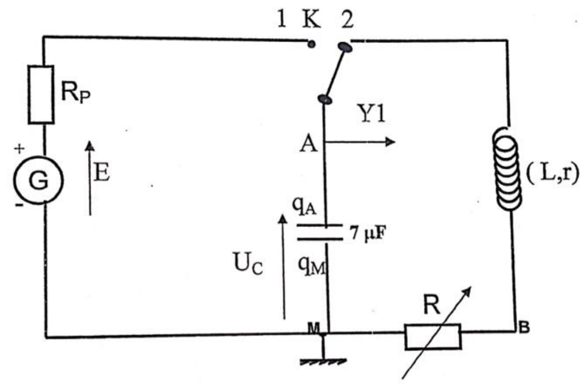
- Distinguish between the different regimes of the discharge of a capacitor in an inductor.
- Know the influence of the resistance of the RLC circuit on the damping.
- Interpret the curves in terms of the transfer of energy stored in the capacitor and inductor and interpret the maintenance of the oscillations.

Materials needed

- GLX interface (The interface can record data and measure against time)
- Voltage sensor/intensity.
- Computer
- DATA STUDIO software (the software that analyses the data from the experiments and makes representations of the data)
- Adjustable DC voltage generator
- A variable resistor, variable capacitor, variable inductance inductor
- Protective resistor, electric wires, electric switch
- Operational amplifier, power supply

Manipulation 1

Make the following assembly:



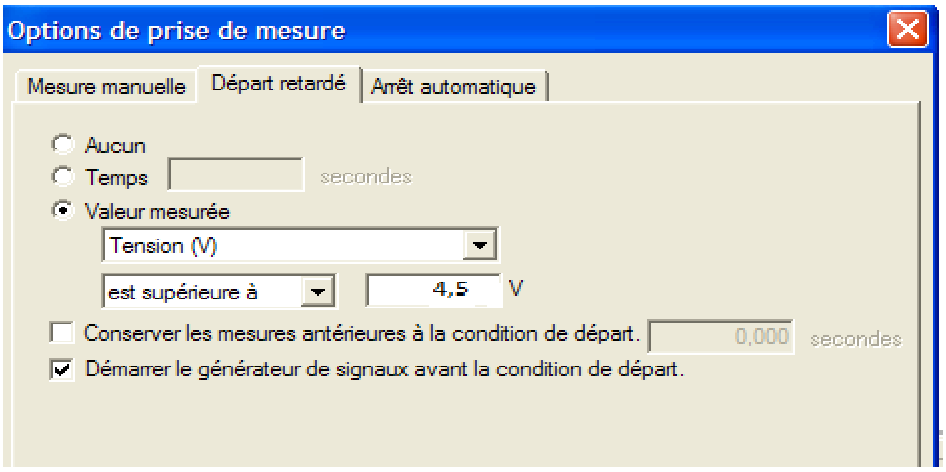
We can take for example r_p = 10kΩ, C = 7µF, L = 1, 1H, R = 20Ω then R = 100Ω then R = 1000Ω.

Connect the DC voltage generator and set it to 5V.

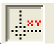
First set the switch to position 1 to charge the capacitor.

In the “Configure” menu:

- Select 1000Hz measurement frequency.
- Click on “Sampling Options”. In the “Delayed Start” tab, → “Measured value”, → Voltage (V) → Falls below 4.5V → OK.
- “Sampling options” → Automatic stop → Time → .25s → OK.



Start, then switch to position 2 for capacitor discharge.

Using the analysis tool  found in the graph toolbar, measure the Eigen period T_0 oscillations and check that the relationship $T_0 = 2\pi\sqrt{LC}$ is correct.

Manipulation 2

The aim of the experiment is to draw the curves E_e, E_m, E_t knowing that $r_p = 10k\Omega$, $C = 7\mu F$, $L = 1$, 1H, $R = 20\Omega$.

- $E_e = ½ C \times U^2$

Calculate → New → Definition: $E_e = ½ \times 7 \times 10^{-6} \times X^2$ → Variable X → Measured Value → Voltage → OK → Accept.

- $E_m = ½ L \times i^2$

Calculate → New → Definition: $E_m = ½ \times 1.1 \times X^2$ → Variable X → Measured Value → Voltage → OK → Accept.

- $E_t = E_e + E_m$

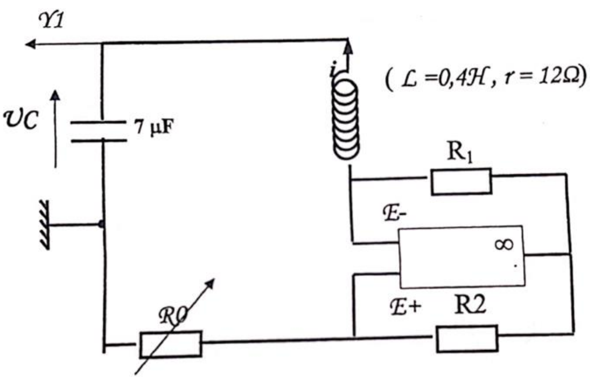
Calculate → New → Definition: $E_t = X_1 + X_2$ → Accept → Variable

X_1 → Measured value → E_e → OK.

X_2 → Measured value → E_m → OK.

Manipulation 3

Carry out the following assembly:



View the voltage across a capacitor at R_0 = (0, 20, 1k)Ω.

- $R_1 = R_2$ = 1KΩ
- Configure → 1000 HZ
- Click on "Sampling Options". In the "Auto-stop" tab → time → 60ms
- R_0 = 0Ω → Start
- R_0 = 20Ω → Start
- R_0 = 1kΩ → Start

Appendix II

Pre-test

MCQ

1. Fouad be able to make an oscillator using any capacitor of capacity C and any inductor of inductance L, such that the period of this oscillator is $T0 = \pi LC^2$.

   Choose the correct answer.

   □ True □ False
2. When we decrease the value of the resistance in an electric circuit (L, C), we decrease its damping time.

   Choose the correct answer.

   □ True □ False
3. If we increase the capacitance of a capacitor in an electric circuit (L, C), we increase the natural period of the oscillator.

   Choose the correct answer.

   □ True □ False
4. If the capacitance of the capacitor and the inductance of the inductor in an electrical oscillator (L, C) are multiplied by four, the value of the natural period is multiplied by 4.

   Choose the correct answer.

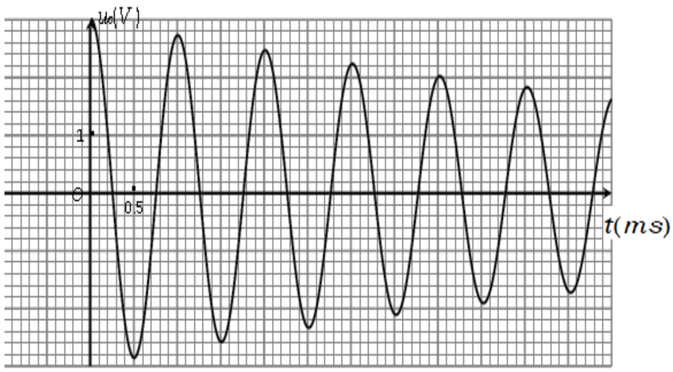
   □ True □ False
5. In an RLC circuit, the energy stored in the initially charged capacitor will be fully transmitted to the inductor.

   Choose the correct answer.

□ True □ False

Exercise

We have a series circuit (R, L, C). The capacitor has a capacitance C = .25μF, initially charged by a generator E = 6V and of negligible internal resistance, and the inductor has a resistance r and an inductance L. Using an oscilloscope, we visualize the evolution of the voltage $u_c(t)$ across the capacitor and obtain the following graph:



1. What is the oscillation regime?
2. How is the damping of oscillations explained?
3. Measure the pseudo-period T of the oscillations.
4. Give the expression of the natural period T_0 of these oscillations.
5. Calculate the value of the inductance L of the inductor, knowing that the pseudo-period is equal to the natural period.
6. To maintain these oscillations, we connect in series a voltage generator such as $u_g = R_0 \times i$ with the circuit (R, L, C). For what value of R_0 does it produce undamped oscillations?

Appendix III

Post-test

MCQ

1. In an RLC circuit, if we double the value of L, the pseudo-period of the oscillations will be multiplied by two.

   Choose the correct answer.

   □ True □ False

2. In an RLC circuit with pseudo-periodic oscillations, L = 0.5 H and we want T_0 = 20ms for the pseudo-period of the oscillations. Should we choose the capacitor capacity?

   Choose the correct answer.

   □ 20μF □ 3μF □ 5mF

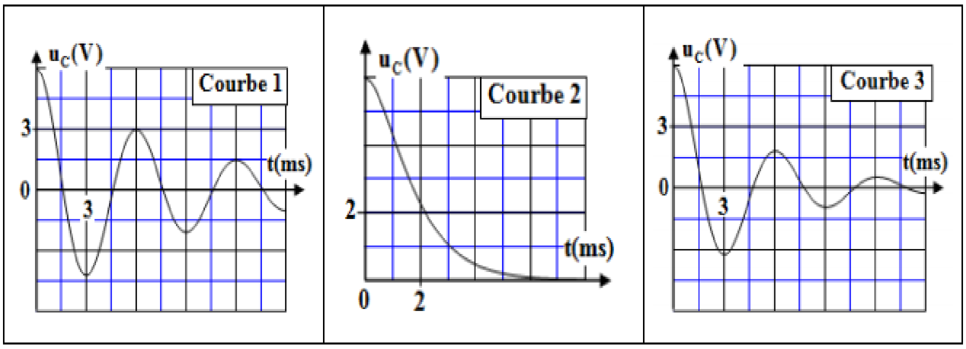
3. As the value L of the inductance of an RLC circuit decreases, the damping of oscillations in the circuit decreases.

   Choose the correct answer.

□ True □ False

Exercise 1

The inductor of inductance L = 60mH and the previous ohmic conductor are connected in series with a capacitor of capacity C previously charged. Curves 1, 2, and 3 show the variations of the voltage $u_c(t)$ between the terminals of the capacitor for different values of the resistance of the ohmic conductor.



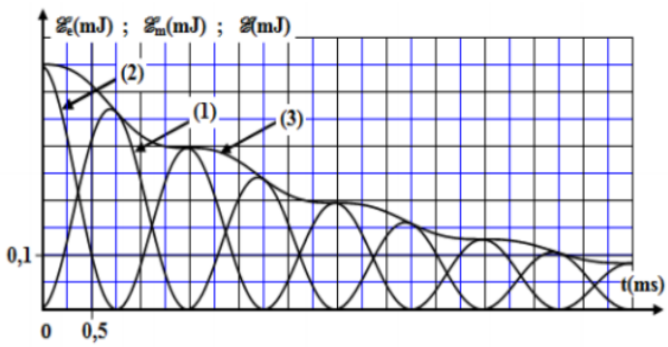
1. Complete the following table by linking the number of the curve to the value of the corresponding resistor R.

	R = 10 Ω	R = 20 Ω	R = 123 Ω
numéro de la courbe	……	……	….

2. Consider curve (1)
   - Give the value of the pseudo-period T of the electrical oscillations.
   - Assuming that the pseudo-period T is equal to the natural period T0 of the free oscillations of the oscillator (LC), check that the value of the capacitance is C = 15µF.
   - To maintain these oscillations, a voltage generator is connected in series such that ug = $R_0 \times i$ with the circuit (R, L, C). For what value of R0 does it produce undamped oscillations?

Exercise 2

The curves represent the variations with time of the electrical energy E_e stored in the capacitor, the magnetic energy E_m stored in the coil, and the total energy E_T of the circuit, such that $E_T = E_e + E_m$.



1. Give the curve corresponding to the magnetic energy E_m and justify your answer.
2. Determine, between the instants $t_0 = 0$ and $t_1 = 3ms$, the variation ΔE of the total energy of the circuit.

Appendix IV

Interview protocol

Initially, the content of the question grid was developed in agreement with the high school physical science teachers.

Open-ended questions:

- Did you encounter any difficulties when learning about free oscillations in an RLC circuit?
- What are the barriers and benefits of integrating CAEx into the learning process?
- What is the added value of using CAEx?

Closed questions with 0 and 1 coding:

- Does the use of CAEx save time?

  □ Yes (0) □ No (1)

- Does the use of CAEx improve the motivation of students and help them to better approach scientific concepts?

  □ Yes (0) □ No (1)

- Does CAEx E facilitate the development of teamwork and problem-solving skills?

  □ Yes (0) □ No (1)

- Does CAEx facilitate the development of independent learning skills and develop critical thinking skills by comparing theory with results?

  □ Yes (0) □ No (1)

- Does CAEx simplify the concept of measurement uncertainty?

  □ Yes (0) □ No (1)