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ORIGINAL ARTICLE

Using MATLAB for Teaching Physics, Direct Current Circuits Problems Case Study

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ABSTRACT

Physics, even though it is guided by simple principles, tends for many topics to be obscured in the mathematics redundancy. MATLAB®, as interactive software for computer algebra, has already had an important impact on the way physics is taught by educators. It has also had a substantial impact on the way research is performed by students to overcome the detention of mathematical difficulties. The literature comparing MATLAB® with other programming languages used in teaching is addressed here in brief, along with the reasons why we choose MATLAB®. This paper aims to introduce, through some examples, the convenience of using MATLAB®, both for teaching and learning physics, by taking advantage of its computation power so that one can concentrate on applying the principles of *setting equations* instead of the technical details of *solving equations*. Some examples found in physics textbooks are analytically solved. We have developed MATLAB® codes regarding these examples as special cases that can be generalized for analyzing electrical direct current circuits. We conclude that the user-friendly environment of MATLAB®, with its powerful built-in routines for a variety of computations, is an effective tool to teach circuit analysis to physics students.

KEY WORDS: Computer simulation, direct current circuits, MATLAB® application, teaching with computer

INTRODUCTION

The fact that teaching as a complex activity involving many kinds of knowledge is on basis of introduction of the Technological Pedagogical Content Knowledge (TPACK) framework by Mishra and Koehler (2006). Their study emphasizes that "*developing theory for educational technology is difficult because it requires a detailed understanding of complex relationships that are contextually bound*" (Mishra, 2006).

Most physics textbooks were published long before modern computer software became widely and easily accessible. The majority of practical applications of physical theory are neglected in these textbooks, with entire paragraphs dedicated to executing long and complicated mathematical operations. Technology, as a teaching tool that helps with learning implementation, has been utilized in physics teaching since the early days. In the modern pedagogical models, knowledge about the (a) content, (b) pedagogy, (c) technology, and (d) their intersections is necessary for developing teaching (Taşar et al., 2023). Using TPACK as a framework for measuring teaching knowledge could potentially have an impact on the type of training and professional development experiences that are designed for teachers (Schmidt et al., 2009).

Because physics is dull, students are not motivated to learn it, which leads to low learning outcomes. The examples included in textbooks are simplified physical conditions that do not accurately reflect reality. Physics is actually a subject that can be taught using a variety of technologies, and aside from paper, pencil, and chalkboard, physicists have always used experimental apparatus, instruments, and devices for in-class demonstrations, simulations, and experiments. The STEM approach to education is closely linked to learners' new literacy skills by facilitating virtual lab activities, linking physics concepts to real-world situations, and offering insight into physics applications.

Technology knowledge, according to Schmidt et al. (2009), is defined in the TPACK framework as "*knowledge about a variety of technologies including low-tech technologies like pencil and paper as well as digital technologies like the Internet, digital video, interactive whiteboards, and software programs*." In today's classroom setup, teachers and students frequently use digital equipment, such as smart boards, mobile devices, such as tablets and smartphones, digital cameras, and computer screen-based simulations. Children of today are frequently referred to as the "*digital natives*" since they are born surrounded by hi-tech equipment that are now a daily encounter, but a time ago, they were impossible even to dream of. (Tasar, 2023).

In this descriptive teaching case study, it is examined the use of MATLAB® to facilitate the analysis of direct current (DC) circuits in a physics teaching context. Presenting how MATLAB® can be used to demonstrate basic ideas, encourage student inquiry, and improve DC circuit analysis problem-solving is the main focus. The study primarily focuses on discussing the development and application of educational resources pertinent to this specific area of physics. It also examines the pedagogical effects related to the benefits of understanding physics concepts.

Students may find it difficult to relate abstract concepts to real-world applications when using traditional teaching methods, which often mostly rely on spoken lectures and static diagrams (Utari et al., 2021). Many textbooks solely cover the theory of numerical methods, ignoring the requirement for programming abilities to use them (Azemi, 1996). Therefore, it is necessary to provide more engaging and dynamic digital teaching resources. To assist students and teachers, computer simulations built with different programming languages on ever-more-powerful computers are becoming increasingly prevalent in the teaching-learning process. A lot of articles are published by many researchers, such as (Perkins et al., 2006; McKagan et al., 2008; Utari et al., 2021), referring to the techniques of using computer hardware and software in learning environments.

Many other researchers, such as (Perkins et al., 2006; McKagan et al., 2008; Wieman et al., 2008; Osmanaj et al., 2021) have published papers with regard to the advantages of using simulations and virtual laboratories during physics teaching.

The *Physics Education Technology* (*PhET*) project (http://phet.colorado.edu) has developed more than 110 interactive physics simulations[1] that are used worldwide, covering various topics in physics and real-world applications. One of the key components of effective simulations is that students enjoy exploring them and learn in the process abstract concepts about science (Wieman et al., 2008). An accurately developed simulation directs the student's attention toward the fundamentals of physics ideas. Some recommendations for using *PhET* simulations as a stand-alone learning tool in various learning environments are given in (Perkins et al., 2006), who also highlight the links between the science and real-world phenomena, concluding that the sims are most effective when students' exploration is somewhat guided by the instructor. In Osmanaj et al. (2021), it is claimed that although Albanian teachers appear to be "*not so friendly*" with simulations and prefer conventional teaching methods, using *PhET* simulations boosts students' interest in physics and improves their comprehension of physics concepts.

Researchers, such as (Azemi, 1996; Cañizares and Faur, 1997; Perkins et al., 2006; Osmanaj et al., 2021), emphasize the many advantages of using computer tools to more clearly convey the educational content to the student, as well as the facilities they create for a deeper understanding of scientific concepts by the latter. On the other hand, certainly computer use may have potential disadvantages that the literature makes little reference to, discussed in (Azemi, 1996), and (Cañizares and Faur, 1997), reaching the conclusion that the advantages fully outweigh the disadvantages. Some drawbacks of educational computer packages are: (i) The need to maintain and run the apps on a computer system, (ii) the additional effort required by instructors and students to become proficient with them, and (iii) making sure the packages are part of the core curriculum (Azemi, 1996).

LITERATURE REVIEW

Divergent opinions exist about the integration of technology in educational settings, and a recent study has concentrated on the issue of how teachers should use various forms of technology in the classroom. The TPACK framework, establishing the relationship between scientific content, teacher, and student, did not emerge suddenly out of nowhere, but there is much background work conducted by others in the previous decades (Taşar et al., 2023). TPACK, as a comprehensive and still developing theoretical framework that describes the body of knowledge needed for successfully integrating technology into their teaching, is described in a very well-structured way in (Taşar et al., 2023).

Many research are carried out with regard to teachers' TPACK and student learning, but "*none explored the correlation between teachers' TPACK and the achievement of their learners*" (Kotoka and Kriek, 2023). Often, the concepts of electricity as part of classical physics, and in our experience, the analysis of DC circuits too, are considered a bit confusing. In their study, Kotoka and Kriek (2023) explored the perceptions of students about their teachers' ICT skills and established a correlation between physics teachers TPACK and the achievements of their students in electricity.

There are several software and programming languages that are used during teaching physics. The challenge is to choose the one that provides the best support to the student in performing the implementation part of the problem-solving task (Fangohr, 2004). A detailed description and comparison of some of these languages is given in Fangohr (2004), Chonacky and Winch (2005), and Ozgur et al. (2021).

Python is a free high-level language that is increasingly used in academia. The author of Fangohr (2004) describes some of *Python's* advantages with regard to teaching, emphasizing its "*clear and intuitive syntax as well as its core of commands that provide the functionalities that beginners require*". The same author considers as an "*important feature for teaching purposes the ability of MATLAB® to have interactive sessions*" (Fangohr, 2004). The authors of (Ozgur et al., 2021) consider as the largest advantage of MATLAB® the ease of producing data visualization while allowing users "*to get a more intuitive read on their data*", instead of relying on coding knowledge. According to Niazai et al. (2023), MATLAB's licensing fees can be a major deterrent for lone researchers, universities, and smaller businesses, possibly preventing them from taking advantage of its potential. Nevertheless, the MATLAB® package, when purchased, comes with everything you need, while using *Python* necessitates installing additional packages (Ozgur et al., 2021). *MathWorks®* provides unlimited access to

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[1] Available online at: *https://phet.colorado.edu/en/simulations/filter?subjects=physics* (retrieved on 30.01.2025)

all its products through Campus-Wide Licenses (MathWorks Company Fact Sheet, 2024).

In MacDonald (1997) there are discussed four reasons for using *Mathematica* in physics instruction*:* (i) Direct students' attention toward the fundamentals of physics rather than "tricks" for solving problems; (ii) teach them how to investigate realistic physical systems using numerical methods and approximations; (iii) use graphics to gain understanding of physical systems and the interaction of physics laws; (iv) teach them how to use technology to improve their skills. *Mathematica* offers unique capabilities for research and education in physics being a powerful language for doing symbolic and numerical computations and for using graphics. However, few students learn to use it comfortably and many become extremely frustrated because they cannot do what they want with it (MacDonald, 1997). MATLAB*'s* origins in numerical computation, in contrast to both *Maple* and *Mathematica*, which highlight their symbolic computing roots, is the reason why MATLAB® is more popular in the engineering community than in the scientific community (Chonacky and Winch, 2005). The list of specialized toolboxes inside its modular architecture demonstrates the many applications in which the product has shown its usefulness and worth.

A lot of publications, such as (Perkins et al., 2006; McKagan et al., 2008; Osmanaj et al., 2021), point out the fact that students respond positively to surveys regarding the help provided by the use of computer tools, and especially the use of MATLAB® (Wakil et al., 2019; Humble, 2021; Utari et al., 2021; Kalsum and Fathurohman, 2023; Ahmed, 2024), in understanding the concepts of the different disciplines of physics.

The study outlined in (Kalsum and Fathurohman, 2023) seeks to (i) identify the challenges students encounter when utilizing MATLAB® and (ii) to assess how they respond to this software throughout their physics education, coming to the conclusion that it is a helpful tool for learning physics. According to the findings of a questionnaire survey given to physics instructors about the use of MATLAB® in the teaching process, learning physics with MATLAB® significantly enhanced student learning outcomes and increased student motivation (Kalsum and Fathurohman, 2023). It is noted in (Utari et al., 2021) that (i) experts believe MATLAB® is suitable to teach physics, and (ii) students responded favorably to it. A recent study, such as (Ahmed, 2024), describes how pre- and post-tests, as well as qualitative surveys, are used to assess how MATLAB® visualizations affect student comprehension and engagement. The results show that learning of physics concepts has significantly improved, with 90% of respondents finding MATLAB® "*more effective than traditional lectures*" and 65% describing their experience with it as "*excellent*" or "*good*" (Ahmed, 2024).

The primary advantage of utilizing MATLAB® codes is the rapid and accurate analysis of physics-related applications in courses. MATLAB®, as a sophisticated programming language, offers an interactive, user-friendly environment, which supports not only numerical commands but also graphical ones for 2D and 3D data analysis and presentation (Wilson, 2003). Nowadays, according to the *MathWorks®* company fact sheet: "*More than 6,500 colleges and universities around the world use MATLAB® and Simulink for teaching and research in a broad range of engineering and science disciplines. There are 5 million users worldwide and 2,500 MATLAB® and Simulink based books published in 27 languages*" (MathWorks Company Fact Sheet, 2024). This is also urged by the decreasing costs of computers, as well as by the increasing number of people who are becoming familiar with advanced analytical methods. MATLAB®, with its features, facilitates program development with excellent code error diagnostics and tracing capabilities (Wilson, 2003). The variety of commands allows users to simply, quickly, and accurately perform those complex mathematical calculations that require time and effort. Such advanced features significantly reduce the time of obtaining the result. MATLAB® is considered by many authors as more effective than other software (Wilson, 2003; Karris, 2003; Ogbuka et al., 2008). Consequently, the facilities it offers allow students to dedicate more time to the primary purpose of calculations, which is: a deeper understanding of the behavior and functioning of physical systems. It is noted in Niazai et al. (2023) that MATLAB® has become an essential resource in resolving the shortcomings of traditional teaching approaches to successfully support learning in a subject that necessitates interaction and visualization.

Students can explore advanced physical applications with MATLAB® despite the mathematical complexity, as well as teachers can use it without being limited by the students' mathematical abilities. The ease with which it can produce graphics – the best way to understand physics – is an important feature of MATLAB®. Describing interactive learning techniques based on using MATLAB® software as a tool to teach math and science, in (Azzam and Al-Kayyali, 2020), it is presented an integrated learning practice for STEM. To make science learning more motivating and long-lasting for students, it is also stressed the fact that more study and discussion are needed on STEM education experiences and teaching strategies (Azzam and Al-Kayyali, 2020).

Research in disciplines including physics, chemistry, biology, geology, and environmental sciences is being revolutionized by MATLAB®, which makes data analysis easier, helps with modeling and simulation, improves image processing, and provides tools for engineering, environmental sciences, and computational chemistry (Niazai et al., 2023). Scientists can produce powerful images for efficient communication thanks to its data visualization features.

METHODS

Considering all the above, we have chosen to use MATLAB® as an additional tool for teaching the DC circuits. Another reason for this choice is the fact that we find it more comfortable to use MATLAB® in the classroom environment because our students, who study physics, must simply possess fundamental coding skills. They are more familiar with MATLAB® because this language is part of their study program curricula. Five problems/examples and the corresponding solutions in MATLAB® are given below regarding all the DC circuit configurations. Mathematical solutions to the problems are outlined together with the results of the calculations, without going into the details of the transitional steps of the solution. In using MATLAB®, as with any other programming language, solving a physics problem requires having accurate input data. MATLAB® executes calculations in such a way that allows the student to focus on the elegance of physical ideas rather than "getting lost in the labyrinths" of the mathematical apparatus.

The codes we developed calculate numerical results by applying in MATLAB® the theoretical general solution found in textbooks. We do not use MATLAB® here for solving differential equations. We found this way more effective, considering the students' knowledge in the mathematical theory of differential equations is basic, but also, we aim to attract their attention in interpreting the graphs generated for various sets of given data.

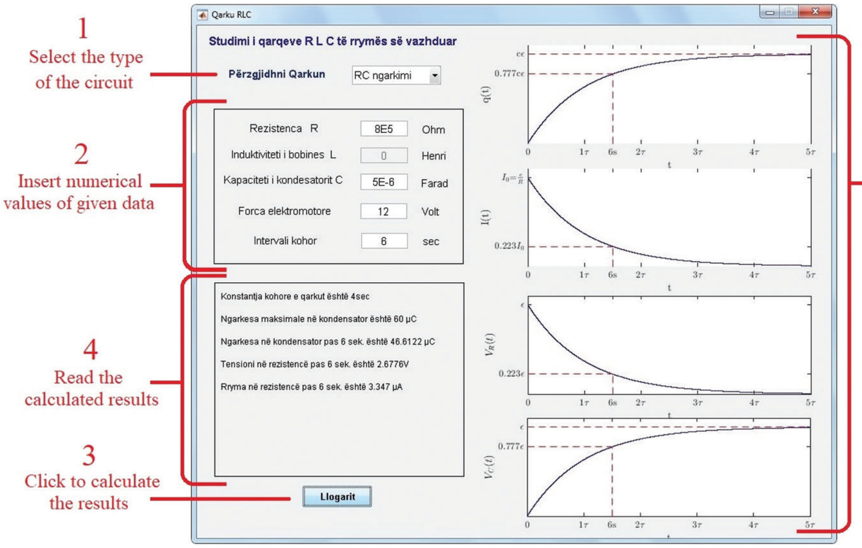
Many of the problems with regard to simple DC electrical circuits require solving differential equations, which the students find difficult sometimes. MATLAB® is especially helpful in this framework. During our experience with teaching physics, we have noticed that it is time-consuming to fully elaborate the mathematical solution of differential equations required for analyzing the series DC circuits. Often the students, instead of focusing in understanding the physical concepts, get confused trying to find the exact numerical values of calculated physical quantities. Hence, by developing a computer code for this purpose, benefiting from the easiness of MATLAB® to perform calculations and plotting, we designed a simple but helpful interface, as shown in the Figure 1 below. By inputting in the interface, the given values of known parameters, students focus on interpreting the results rather than executing calculations. On the other hand, as they are not professional software developers, they find it attractive to edit the code to adapt it for solving similar problems of DC circuits.

We mainly use this interface during teaching problem-solving strategies with the students who attend the Master in Education study program, which prepares them to become physics teachers in pre-university education. These future teachers, during their teaching in high school, will deal with students who do not have the mathematical skills to analytically solve differential equations, which are not part of the high school curricula. Furthermore, we use it when teaching classical electromagnetism to physics students, a course that in their curricula is prior than they get knowledge of differential equations later during their studies. Hence, we focus mostly in interpreting the graphical results rather than on the mathematical steps of analytical problem solving. By changing the input parameters, we found it very helpful to plot graphs repeatedly and analyze the DC series circuit. By allowing students to change variables and see results in immediate view, dynamic representations and interactive simulations can greatly enhance comprehension and help them gain a deeper understanding of concepts.

The local context of the study and the basic prior knowledge of the student, specifically on solving differential equations, might be considered as limitations. However, it can serve as a guide to science educators on how to transfer the findings to other instructional levels and settings.

In physics textbooks can be found the formulas, summarized in Table 1, used to calculate the quantities for analyzing the DC circuits, respectively, *RC charging* (Figure 2a), *RC discharging* (Figure 2b), and *RL circuit* (Figure 2c).

In Figure 2d, an LC circuit is shown. In an idealized situation where the resistance in the circuit is zero, and it is not radiated energy away from the circuit, the oscillations of the current in the circuit and the charge on the capacitor continue infinitely,



Studimi i qarqeve R L C të rrymës së vazhduar

Përzgjidhni Qarkun: RC ngarkimi

Rezistenca R: 8E5 Ohm
Induktiviteti i bobines L: 0 Henri
Kapaciteti i kondesatorit C: 5E-6 Farad
Forca elektromotore: 12 Volt
Intervali kohor: 6 sec

Konstantja kohore e qarkut është 4sec
Ngarkesa maksimale në kondensator është 60 μC
Ngarkesa në kondensator pas 6 sek. është 46.6122 μC
Tensioni në rezistencë pas 6 sek. është 2.6776V
Rryma në rezistencë pas 6 sek. është 3.347 μA

1 Select the type of the circuit

2 Insert numerical values of given data

3 Click to calculate the results

4 Read the calculated results

5 Analyze the graphs generated

Figure 1: RC circuit, charging the capacitor, MATLAB® solution of Example 1

Table 1: Summary of formulas for RC charging, RC discharging, and RL circuits

Quantity	RC charging	RC discharging	RL circuit
Time constant τ	$\tau=RC$	$\tau=RC$	$\tau=L/R$
Maximum charge Q	$Q=C\varepsilon$	$Q=C\varepsilon$ (initial charge)	Not applicable
Charge	$q\ (t) = C\varepsilon\ (1-e^{-t/RC})$	$q\ (t) = C\varepsilon\ e^{-t/RC}$	Not applicable
Voltage across resistor	$V_R\ (t) = \varepsilon \cdot e^{-t/RC}$	$V_R\ (t) = \varepsilon \cdot e^{-t/RC}$	$V_R\ (t) = \varepsilon \cdot (1-e^{-Rt/L})$
Voltage across capacitor	$V_c\ (t) = \varepsilon\ (1-e^{-t/RC})$	$V_c\ (t) = \varepsilon \cdot e^{-t/RC}$	Not applicable
Voltage across inductor	Not applicable	Not applicable	$V_L\ (t) = -\varepsilon \cdot e^{-tR/L}$
Current in circuit	$I(t)=\frac{\varepsilon}{R}\cdot e^{-t/RC}$	$I(t)=-\frac{\varepsilon}{R}\cdot e^{-t/RC}$	$I(t)=\frac{\varepsilon}{R}\cdot\left(1-e^{-Rt/L}\right)$

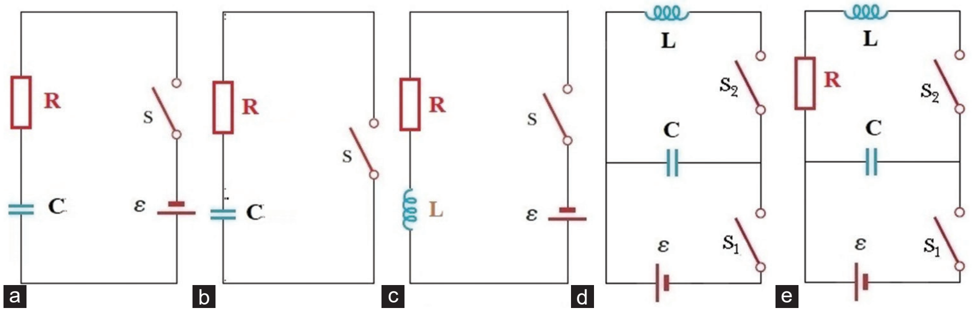


Figure 2: (a) capacitor and resistor in series with the battery; (b) the charged capacitor in series with a resistor; (c) resistor and inductor in series with the battery; (d) oscillatory LC circuit; (e) oscillatory RLC circuit

similarly to the mechanical oscillations in the frictionless system mass-spring.

A more realistic situation is the *RLC circuit* presented in Figure 2e. In this circuit, the total energy is not constant (as it was in the RL circuit), because the resistance causes transformation of energy into inner energy. The RLC circuit, analogous to the damped oscillations in a mass-spring system oscillating in a viscous liquid. In the simplest case, when $R=0$, the discussion is reduced to the situation of an LC circuit: the charge and the current oscillate sinusoidally.

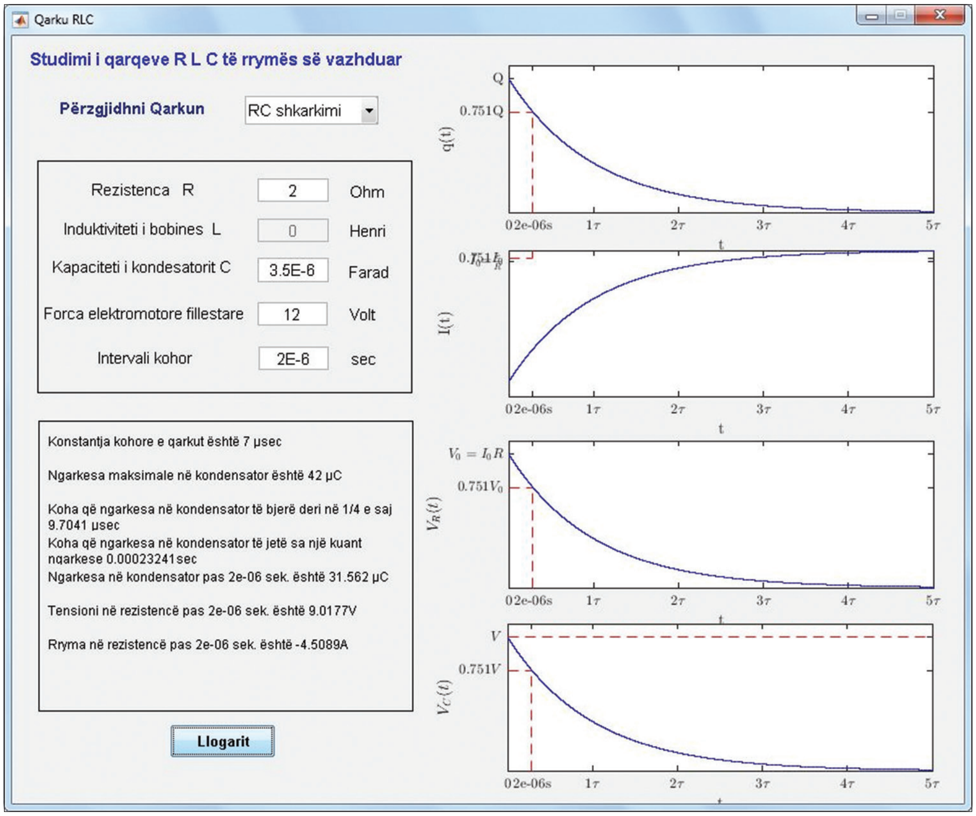
RESULTS AND DISCUSSION – TEACHING DC CIRCUITS WITH MATLAB

Analytical solutions are given below for some examples adapted from two of the most popular physics textbooks at the college and university levels, such as (Serway, 2018), and (Young and Freedman, 2020). During the teaching of DC circuits, we provide the answers given by the execution of the MATLAB® code we developed for these same examples to assist students in drawing comparisons between the two techniques of solving. Furthermore, we highlight MATLAB® numerical computations' accuracy. The most intriguing benefit of using our generated MATLAB® code/interface with our students is how it can be reused as many times as necessary, allowing for the simple modification of the physical quantities' numerical values to provide a variety of graphical outcomes for comparison.

Although a formal survey or questionnaire was not conducted, the use of MATLAB power in calculating and plotting seemed to offer a number of pedagogical benefits in teaching DC circuits. The accuracy and readability of MATLAB visuals enhanced our classroom experience and promoted a more participatory learning environment by simplifying circuit complex ideas. Deeper student engagement and inquisitive learning were promoted by the capability to dynamically modify parameters and instantly see the impact on circuit behavior. Following the adoption of MATLAB-based training, students' performance on tests and problem-solving exercises significantly improved, indicating a beneficial effect on conceptual understanding. These findings demonstrate that MATLAB can be a useful teaching tool in physics education, even though they are mostly based on the instructor's observations.

We have developed codes in MATLAB® for each type of series DC circuits: RC charging; RC discharging; RL; LC; and RLC circuits. With our students, we use in these codes the numerical data of each example, aiming for two things: (i) To check the accuracy of analytical solutions; and (ii) by letting the students change the numerical data in the code, they can focus on interpreting the graphs generated, rather than repeating time-consuming calculations for the same type of example. On the other hand, the examples above are chosen just as typical comprehensive problems solved/taught in this part of physics.

We have developed a simple but user-friendly interface composed of 5 sections, as shown in Figure 1, about which the students have shared their opinion of being "*comfortable*" using it. The students start using the interface by selecting the type of circuit they wish to analyze in the drop-down menu



Përzgjidhni Qarkun: RC shkarkimi

Rezistenca R: 2 Ohm
Induktiviteti i bobines L: 0 Henri
Kapaciteti i kondesatorit C: 3.5E-6 Farad
Forca elektromotore fillestare: 12 Volt
Intervali kohor: 2E-6 sec

```
Konstantja kohore e qarkut është 7 µsec

Ngarkesa maksimale në kondensator është 42 µC

Koha që ngarkesa në kondensator të bjerë deri në 1/4 e saj
9.7041 µsec
Koha që ngarkesa në kondensator të jetë sa një kuant
ngarkese 0.00023241sec
Ngarkesa në kondensator pas 2e-06 sek. është 31.562 µC

Tensioni në rezistencë pas 2e-06 sek. është 9.0177V

Rryma në rezistencë pas 2e-06 sek. është -4.5089A
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Figure 3: RC circuit, discharging the capacitor, MATLAB® solution of Example 2

at the far upper left corner; then they insert in the upper left box of the interface the numerical data given; and finally, the calculated results are shown in the lower left box or plotted on the right panel of the interface.

Graphs shown in Figure 1, generated by MATLAB® code we have developed, are consistent with theoretical predictions. Graphs of *charge versus time* (Figure 1) and *current versus time* (Figure 1) show that: the charge is zero at $t=0$ and its maximal value is $C\varepsilon$; the current has a maximal value ε/R at $t=0$ and decreases exponentially.

Furthermore, the graphs of Figure 1, generated by MATLAB® code we have developed show the *voltage drop* across the capacitor and the resistor. By increasing the charge in the capacitor, the current decreases (Figure 1) while the voltage across the capacitor increases.

Students follow the specific mathematical procedures that result in the numerical values of specific physical quantities when the instructor explains the capacitor charge in the RC circuit, as shown in Example 1. It has frequently been noticed that students must invest a significant amount of time and frequently produce inaccurate numerical results because to the intricate computations required to solve identical problems analytically. In addition to creating graphs showing the temporal dependences of voltage and current, we also use the MATLAB®-developed code to help students to confirm the precision of their computations. To assess the accuracy and, more importantly, the rapidity of obtaining the numerical result, students compare the results of their calculations with those obtained by the MATLAB® code. This allows them to spend more time to discussing physical notions.

Example 1: Adopted from Example 18.6 in (Serway, 2018) page 604
RC circuit, charging the capacitor, analytical solution

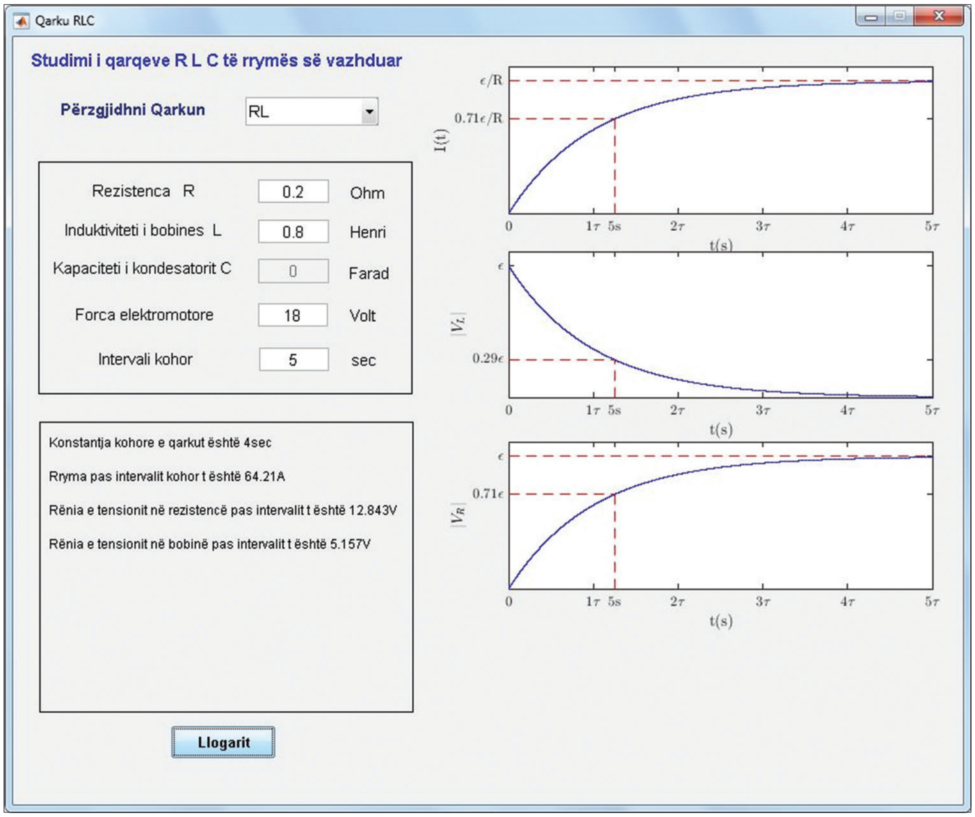
An uncharged capacitor and a resistor are connected in series to a battery, as in Figure 2a. If $R=8\ 10^5\ \Omega$, $C=5\ \mu F$ and $\varepsilon = 12\ V$

Compute	**Analytical solution:**
The time constant of the circuit	$\tau = RC = 8\ 10^5.5.10^{-6} = 4s$
The maximum charge on the capacitor	$Q = C\varepsilon = 5.10^{-6}.12 = 60\ \mu C$
The charge on the capacitor after 6s	$q\ (t=6) = Q\ (1-e^{-t/RC}) = 46{,}6\ \mu C$
The potential difference across the resistor after 6s:	$V_R\ (t=6) = \varepsilon \cdot e^{-t/RC} = 2{,}68\ V$
The current in the resistor after 6s:	$I\ (t=6) = (\varepsilon \cdot e^{-t/RC})/R = 3{,}35\ \mu A$

The graphs in Figure 3, generated by MATLAB® code we have developed, show that the *charge in capacitor* $q(t)$, the *voltage across the capacitor* $V_C(t)$ and *across the resistor* $V_R(t)$, decrease exponentially.

The MATLAB® codes we have developed generate the graphs of Figure 4: *current in circuit versus time* $I(t)$; *voltage across the resistive element versus. time* $V_R(t)$; and *voltage across the inductor versus time* $V_L(t)$. Students can verify the exponential growth of current in circuit and of voltage across the resistor.

As shown in the graphs in Figure 5, the charge on the capacitor



Studimi i qarqeve R L C të rrymës së vazhduar

Përzgjidhni Qarkun RL

Rezistenca R 0.2 Ohm
Induktiviteti i bobines L 0.8 Henri
Kapaciteti i kondesatorit C 0 Farad
Forca elektromotore 18 Volt
Intervali kohor 5 sec

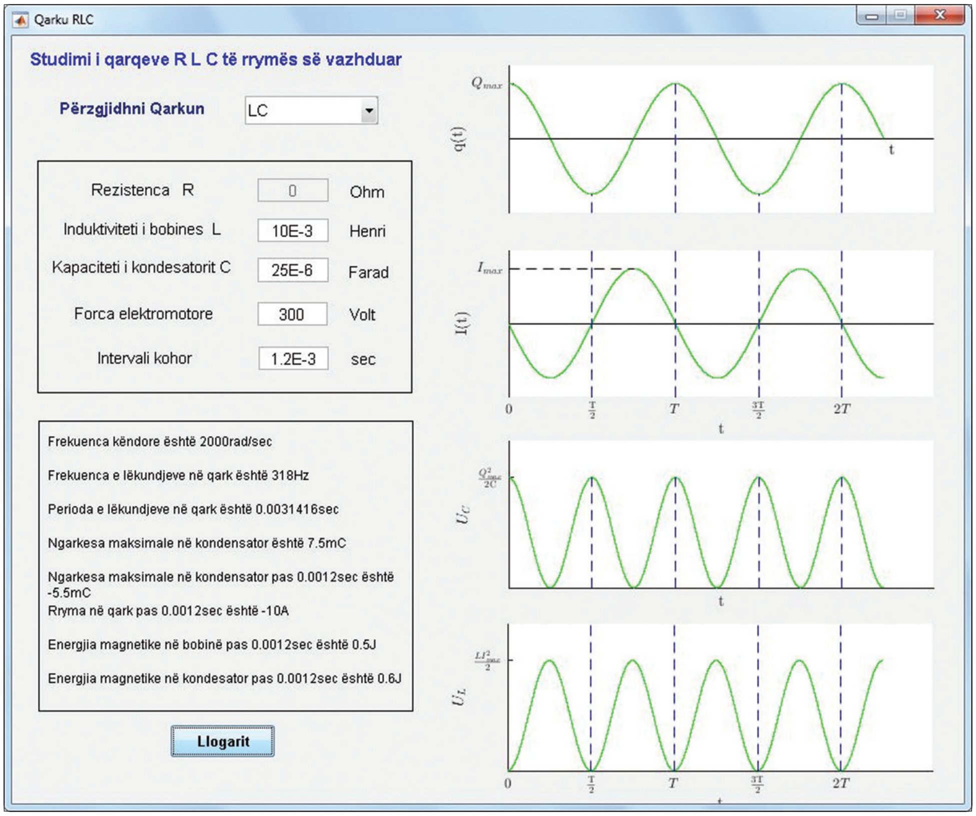
Konstantja kohore e qarkut është 4sec

Rryma pas intervalit kohor t është 64.21A

Rënia e tensionit në rezistencë pas intervalit t është 12.843V

Rënia e tensionit në bobinë pas intervalit t është 5.157V

Figure 4: RL circuit, MATLAB® solution of Example 3



Studimi i qarqeve R L C të rrymës së vazhduar

Përzgjidhni Qarkun LC

Rezistenca R 0 Ohm
Induktiviteti i bobines L 10E-3 Henri
Kapaciteti i kondesatorit C 25E-6 Farad
Forca elektromotore 300 Volt
Intervali kohor 1.2E-3 sec

Frekuenca këndore është 2000rad/sec

Frekuenca e lëkundjeve në qark është 318Hz

Perioda e lëkundjeve në qark është 0.0031416sec

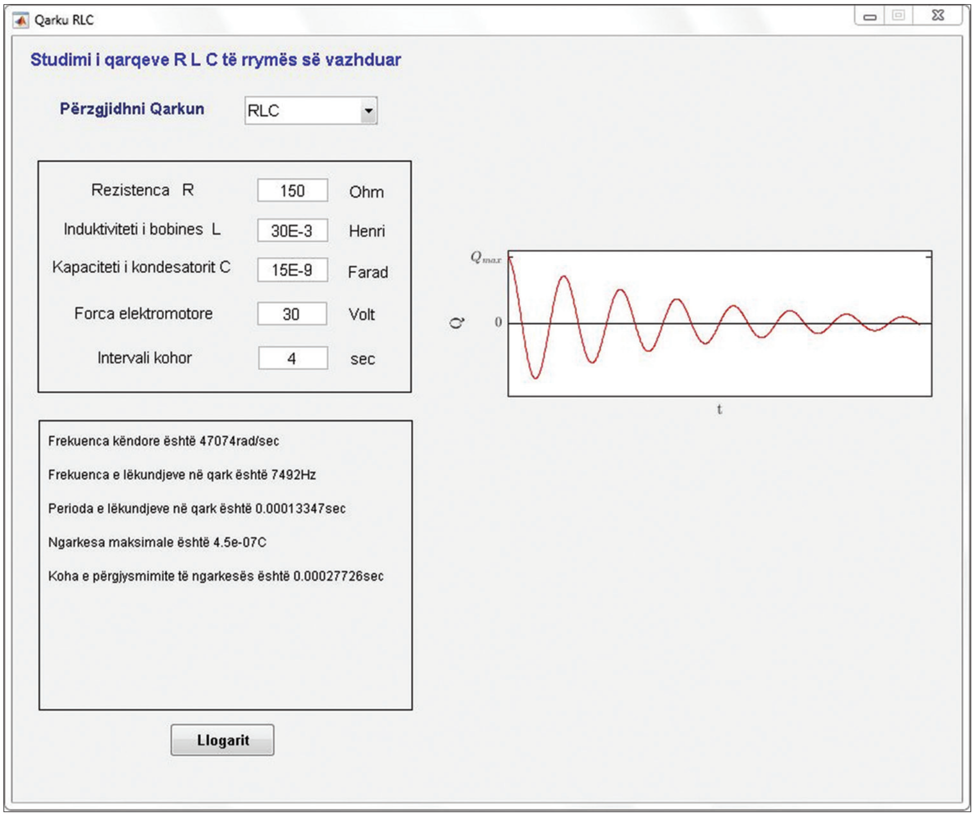
Ngarkesa maksimale në kondensator është 7.5mC

Ngarkesa maksimale në kondensator pas 0.0012sec është -5.5mC
Rryma në qark pas 0.0012sec është -10A

Energjia magnetike në bobinë pas 0.0012sec është 0.5J

Energjia magnetike në kondesator pas 0.0012sec është 0.6J

Figure 5: LC circuit, MATLAB® solution of Example 4



Qarku RLC

Studimi i qarqeve R L C të rrymës së vazhduar

Përzgjidhni Qarkun: RLC

Rezistenca R: 150 Ohm

Induktiviteti i bobines L: 30E-3 Henri

Kapaciteti i kondesatorit C: 15E-9 Farad

Forca elektromotore: 30 Volt

Intervali kohor: 4 sec

Frekuenca këndore është 47074rad/sec

Frekuenca e lëkundjeve në qark është 7492Hz

Perioda e lëkundjeve në qark është 0.00013347sec

Ngarkesa maksimale është 4.5e-07C

Koha e përgjysmimite të ngarkesës është 0.00027726sec

Figure 6: RLC circuit, MATLAB® solution of Example 5

Example 2: Adopted from Example 18.7 in (Serway, 2018) page 605
RC circuit, discharging the capacitor, analytical solution

A capacitor with capacitance *C*=3,5 *μF* is discharged through a resistor with resistance *R*=2Ω as in Figure 2b. The initial potential difference across the capacitor is ε = 12 V

Compute	Analytical solution
The time constant of the circuit	$\tau = RC$=2 3,5 10^{-6} = 7 μs
The initial charge on the capacitor	Q=Cε = 3,5 $10^{-6} \cdot 12$=42 μC
The time it takes to discharge up to one-fourth of the initial charge	$q\ (t) = Q \cdot e^{-t/RC}$=Q/4 $t = -RC \cdot \ln\ (1/4) = 1{,}39\ \tau = 9{,}73\ \mu s$
The time it takes to discharge all but the last quantum of charge	$q\ (t) = Q \cdot e^{-t/RC}$=1,6 10^{-19} $t = -RC \cdot \ln\ (1{,}6 \cdot 10^{-19}/Q) = 0{,}23\ ms$
The charge on the capacitor after 2μs	$q\ (t$=2 $\cdot\ 10^{-6} = Q \cdot e^{-t/RC}$=31,56 μC
The potential difference across the resistor after 2μs	$V_R\ (t$=2 $\cdot 10^{-6}) = \varepsilon \cdot e^{-t/RC}$=9 V
The current in the resistor after 2μs	$l\ (t$=2 $\cdot\ 10^{-6}) = (\varepsilon \cdot e^{-t/RC})/R$=4,5 A

Example 3: Adopted from Example 20.8 in (Serway, 2018) page 676
RL circuit, analytical solution

A battery with ε = 18 V is in a circuit with a *L* = 0,8 *H* inductor and a *R* = 0,2Ω resistor as in Figure 2c. The switch is closed at t = 0

Calculate	Analytical solution
The time constant of the circuit	τ = L/R = 4s
The current after an interval of 5s has elapsed	$I(t=5) = \frac{\varepsilon}{R}\left(1-e^{-Rt/L}\right) = 64,21A$
The time it takes the current to become 80% of its maximum	$I(t) = \frac{\varepsilon}{R}\left(1-e^{-Rt/L}\right) = 0,8 \cdot I_{\max} = 0,8 \cdot \frac{\varepsilon}{R}$ $1-e^{-Rt/L} = 0,8 \quad \Rightarrow \quad t = 6,44s$
The voltage drop across the resistor after an interval of 5s has elapsed	$V_R\ (t=5) = I_R\ (t=5) \cdot R = 64{,}21 \cdot 0{,}2 = 12{,}84$ V
The voltage drop across the inductor after an interval of 5s has elapsed	$V_L\ (t=5) = -\ \varepsilon \cdot e^{-tR/L} = 5{,}16$ V

oscillates between the values Q_{max} and $-Q_{max}$ and the current is in a 90° phase difference with the charge. By the analytical solution and by the MATLAB® solution, students notice (Figure 5) that the total energy in the circuit after 1,2 ms is: $U(t = 1{,}2\ ms) = U_L\ (t = 1{,}2\ ms) + U_C\ (t = 1{,}2$ ms$) = 0{,}5\ J + 0{,}6\ J = 1{,}1\ J$

By changing the data input of time interval and keeping the same numerical values for inductivity L, capacity C, and voltage ε, students notice in the interface the conservation of total energy in the oscillatory circuit:

$U(t = 5\ ms) = U_L\ (t = 5\ ms) + UC\ (t = 5\ ms) = 0{,}3\ J + 0{,}8\ J = 1{,}1\ J$

$U(t = 6{,}5\ ms) = U_L\ (t = 6{,}5\ ms) + UC\ (t = 6{,}5\ ms) = 0{,}2\ J + 0{,}9\ J = 1{,}1\ J$

Example 4: Adopted from Examples 30.8 and 30.9, in (Young and Freedman, 2020), page 1033
LC circuit, analytical solution

A DC power supply of ε = 300 V is used to charge a C=25 μF capacitor. After the capacitor is fully charged, it is disconnected from the power supply and connected across a L=10 mH inductor. The resistance in the circuit is negligible.

Calculate	Analytical solution
The angular frequency	$\omega = (1/LC)^{½} = 2000\ rad/s$
The frequency	$\omega = 2\pi f \Rightarrow f = 320\ Hz$
The period of the oscillation	$T=1/f=3{,}1\ ms$
The maximum charge on the capacitor	$q_{max}=\mathrm{Q} = \varepsilon_C=7{,}5\ 10^{-3}\ C$
The capacitor charges 1,2 ms after the battery is disconnected	$q\ (t=1{,}2\ ms) = Q\cdot\cos\,\omega t=5{,}5\cdot10^{-3}\ C$
The circuit current 1,2 ms after the battery is disconnected	$l\ (t=1{,}2\ ms) = -\omega\cdot Q\cdot\sin\,\omega t = -10\ A$
The magnetic energy in the inductor after 1,2 ms	$U_L(t=1,2ms)=\dfrac{L\cdot I^2_{(1,2ms)}}{2}=0,5J$
The electrical energy in the capacitor after 1,2ms	$U_C(t=1,2ms)=\dfrac{q^2_{(1,2ms)}}{2C}=0,6J$

Example 5: Adopted from Example 30.38, in (Young and Freedman, 2020), page 1041
RLC circuit, analytical solution

For the circuit of Figure 2e, let C=15 mF, L=30 mH, R=150 Ω and ε = 150 V

Calculate	Analytical solution
The angular frequency	$\omega=\sqrt{(1/LC)-(R/2L)^2}=47047 rad/s$
The frequency	$\omega=2\pi f \quad\Rightarrow\quad f=7,4916kHz\simeq7,5kHz$
The period of the oscillation	$T=1/f=0{,}13\ ms$
The time required for the charge amplitude to drop to half its starting value	$q\ (t) = Q\cdot\mathrm{e}^{-Rt/2L}=\mathrm{Q}/2$ $t = (-2L/R)\cdot\ln\,(1/2) = 277{,}2\ \mu s$
The number of oscillations completed during this time	$No.\ of\ oscillations\ =\dfrac{t}{T}=2{,}13$

The *time dependence of the charge q*(t) is plotted in Figure 6, generated by the MATLAB® code we have developed, using the numerical data of Example 5. The students can easily verify by changing the numerical values of the resistor, that when the R has a large value, the damp is much faster.

CONCLUSION

Learning physics is considered generally "difficult", but on the other hand, even *teaching* physics is not easy. Laboratory experimentations and demonstrations are the best way to transmit abstract concepts of physics. Since different student groups require different teaching methods, it goes without saying that instructors have diverse teaching philosophies based on a variety of factors, including the classroom setting. Yet, it remains a challenge for physics educators to find methods and tools that could be effective in communicating the physics content to students and, at the same time, to fascinate them with physics knowledge. We think that any innovative use of technology in the classroom enhances any traditional lecture-based teaching approach. In a very useful way, the illustrations bring a visually dynamic nature to the lecture presentation.

Computers cannot replace human thinking, but they fundamentally widen the problem-solving abilities that scientists and students encounter by eliminating the mathematical burden. As computers become more powerful and accessible, the variety of problems they solve in both research and teaching is expanding exponentially. For a more in-depth study, MATLAB® also offers other possibilities through the Simulink® package, but it also offers the possibility to create easy-to-use interfaces, which were not the subject of this article.

The interface that we have developed in MATLAB® serves not only to quickly numerically solve the problems of this physics chapter or to accurately visualize graphically the time dependence of physical quantities (such as the charge on the capacitor, the current in the circuit, and the voltage drop in the circuit elements), but it can also be successfully used as an additional tool in the laboratory by the students during experimental practices for the study of DC circuits.

We read through the student interpretations of the graphs created, had casual conversations with them during office hours, and collected feedback at the end of the course. Ultimately, our method proved to have numerous benefits over the conventional textbook examples and questions of this topic on physics.

AUTHORS' CONTRIBUTIONS

I.K.: Conceived of the presented idea, developed the theoretical formalism, drafted the manuscript, designed the figures, and performed the computations. K.L.: Designed the model and the computational framework, planned and carried out the simulations, and contributed to the interpretation of the results. Both authors wrote the manuscript, discussed the results, and contributed to the final manuscript.

DATA AVAILABILITY

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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The authors declare no competing interests.

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