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Simulation of magnetic field produced by induction in toroid and solenoid using GeoGebra software

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Abstract

In today's era of modernity and the appearance of new knowledge-construction approaches supported by technological tools such as A.I., various instruments contribute to enhancing educational quality like GeoGebra, an open-source software with extensive capabilities for simulations. This research established three objectives, all of which are answered in its conclusions. The study focused on simulating magnetic fields with predefined geometric shapes, analyzed using mathematical principles. Computational simulation was the primary methodology, involving the implementation of Ampere's law, Biot-Savart law, and electromagnetism, as well as their applications in solenoids and toroids. The simulations were developed using GeoGebra's virtual simulation tools and Java Script application. As a result, a functional simulation was created to model the behavior of a normally closed solenoid valve, allowing manipulation of parameters such as radius, length, number of turns, diameter and current intensity. Similarly, a toroidal transformer simulation was developed, enabling adjustments to coil count, toroidal surface area, voltage, primary and secondary toroids to control each parameter in the respective model. The discussion highlights that similar applications have been successfully developed by other researchers, demonstrating their effectiveness in supporting university students' learning. The study concludes that simulations significantly strengthen foundational physics knowledge in engineering education.

Keywords: *Solenoid, toroid, magnetic field, Ampere's law, magnetic simulation, GeoGebra simulation, electromagnetic simulation*

Introduction

Virtual education has opened new opportunities for students (Hernández-Sellés et al.,2023), and the discovery of various virtual and computational tools that have enriched the learning process, which has transformed the traditional methods used in university education for centuries.

The Covid-19 pandemic allowed educators to seek substantial and, above all, didactic ways of transmitting knowledge (Salazar-Mata et al, Rosser-Limiñana,2022). Education now plays a critical role in shaping society and its dynamics, requiring an adaptable educational system that responds to evolving contexts and learning needs (Cáceres Mesa et al.,2022), meeting the demands of students, who are also active contributors to society's goals, likewise (Salazar-Mata et al.,2022) refer to this emerging virtual education model as "classrooms without walls" due to its non-traditional, non-face-to-face nature, which prioritizes both synchronous and

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asynchronous modalities (Carrión et al.,2022; Giwanatara et al., 2021), and it is not necessarily based on those borders that have always divided education.

According to how this new modality of university education was implemented, there are different approaches on how to establish and take this opportunity to generate great changes in students and above all how to contribute to the growth of research and technology.

A persistent challenge in many countries, particularly at the secondary and higher education levels, is the lack of laboratory equipment in educational institutions; adequate physics laboratories or specialized facilities are essential for fostering effective and meaningful learning experiences, in Latin American nations and other emerging countries, this issue is compounded by the limited availability of such resources but there is a computational tool within the reach of all students in their study centers, in which research can be carried out through simulations and modeling of the different disciplines of science and engineering.

Unesco (2023), highlights the importance of using technological tools to foster innovation through simulations, facilitating meaningful learning in mathematics and physics courses, governmental institutions show great progress and development mediated by technological tools which open many possibilities to create new instruments capable of providing solutions to problems encountered in the reality of researchers and any student.

Nasa (2021), through the operation of space travel, this institution gathers four crew members for their simulation of trips to lunar satellites, showing the importance of making the crew members can develop the competences and skills for their departure and landing without stepping on the ground of the aforementioned satellites, likewise this type of project reduces the investment of real trips and favors the company and prepares future astronauts.

This is how the technological revolution constitutes a fundamental basis for understanding the behavior of societies (Arévalo et al.,2022), and even new perceptions of how we can conceive what surrounds us and ourselves (Montoya López et al.,2018), where technology is constantly evolving and supporting humanity. In this context, virtual education has brought a significant change, likewise (Engel & Coll 2022), emphasize that distance learning is not only the responsibility of the student but also depends heavily on the teacher and the opportunities they provide, including the development and delivery of instructional materials designed to foster self-directed learning.

It is essential to acknowledge that the combination of virtual learning and the appropriate resources provided by teachers empowers students to actively seek and improve their knowledge through information exploration, therefore it should be considered that in this new reality it is a constant work between the teacher and student to generate a growing new knowledge, as mentioned above.

The proposed objectives developed in the research were: the student can visualize and understand the behavior of the magnetic field, the student can experiment with different parameters used in the dynamic sheet of Geogebra without the need of a physical laboratory to understand the phenomenon of the magnetic field, the students can develop modeling and simulation skills through the equations of Ampere, Biot Savart and other scientists.

(Reina & Silva,2022), highlight the development of neuro education, which plays a significant role in face-to-face, semi face-to-face and virtual education, the new educational approaches allow students to spend more time engaging with electronic devices, facilitating the use of emerging technologies that contribute academically in an autonomous way, making each student a promoter of new approaches and knowledge, similarly (Oliva-Cruz & Mata-Puente,2022), mention that learning during pandemic involves the ability to understand new information and transform it into new knowledge mediated by technology, this process is integral to the academic and professional development of university students throughout their educational journey.

Virtual simulations play an important role in generating new knowledge in research, such as the one developed in engineering classrooms, according to (Lighezzolo et al.,2019) and (Martínez-Palmera et al,2018), the development of the designed research, when complemented by virtual simulators (Ramos et al.,2011), provides a dynamic framework for modeling various aspects of the real world. This holistic approach enables the deployment and analysis of programming tool variables, facilitating the development of new theoretical constructs and their subsequent validation (Belando et al; Soares et al; Cunha, 2024; Jam et al., 2011), (Amores et al.,2022), (Rotz et al.,2019), (Guo et al.,2018) and (Martinez-Perez,2016; Farooq et al., 2010).

This approach can revolutionize the concept of computationally mediated emergent virtual education. (Heidemann et al,2021; Ahmed et al., 2022) and (Ribeiro Junior,2012; Jam et al., 2010), mention that computational simulations help to overcome the inherent limitations of traditional experimental laboratories, including time constraints, high instrumentation costs, operational expenses, the lack of trained personnel for maintenance, and restricted laboratory availability.

This research is justified by the need to develop simulations regarding the explanation of the behavior of solenoids and toroids, due to the lack of information on these crucial physics topics.

According to (Morales & Feo,2016; Shamsuddinova et al., 2021), computer simulations closely replicate the behavior of physical systems and other real-world phenomena, contributing to advancements in research, they also enable the application of established scientific theories to predict system behaviors, similarly (Lu,2022; Ardiansyah et al., 2024; Ghiat, 2017; Savsar et al., 2016) emphasizes that simulations, as a didactic strategy, must meet certain criteria, such as being objective, flexible, participatory, and integrative, to effectively predict outcomes. Similarly, (Bouteraa et al,2020; Jam et al., 2016) highlight the use of simulations to improve the rehabilitation of upper limbs in individuals with disabilities. This underscores the importance of simulations as a holistic learning and research tool, offering significant benefits for enhancing various aspects of human life and driving transformative changes.

Technological advancements, particularly in education, have highlighted the importance of this research in enhancing the understanding of Ampere’s law, the magnetic field in solenoids and toroids, and related principles; this study provides valuable insights into their behavior under varying parameters, enriching the conceptual framework surrounding solenoids and toroids, also the laws applied in their behavior.

In agreement with (Huapaya, 2018; Subhani et al., 2023; Liao et al., 2019), the Biot-Savart law can be used to determine the magnetic field generated by any current distribution. A fundamental approach to analyze magnetic fields involves employing a law that takes advantage of the symmetry in certain scenarios to simplify the calculation of the magnetic field (B). This approach is often considered more efficient than the Biot-Savart law and introduces one of Maxwell’s four equations. This new result constitutes Ampere’s law that can be applied to an electromagnet, which, when activated, conducts an electric current. Electromagnets typically consist of many wire coils, that are in proximity.

(Martínez, 2019) mentions that the solenoid is commonly referred to as an "XR" in various physics textbooks, where it is often presented in a theoretical and generalized manner due to its complexity in experimental applications. The expression $B=\mu_0 nI$ is frequently accepted as a standard approximation for an ideal solenoid, even when this deal condition is not met.

The pedagogical importance of solenoids lies in their application for determining the magnetic field using Ampere's law, calculating the self-inductance coefficient, and understanding key principles in electromagnetism. These processes can be reinforced through conceptual field theory, enabling meaningful learning experiences such as problem-solving, assignments, and assessments (Moreira, 2002; Iriany et al., 2019; Asia et al., 2015). The assumption of a uniform internal magnetic field in a solenoid requires Ampere's law to be effective. If this law were not applicable, the problem might remain unresolved through the Biot-Savart law due to inherent mathematical challenges. Therefore, analyzing problems from multiple perspectives using various laws, grounded in experimentation, is essential for a comprehensive understanding.

The solenoid is commonly used to generate a uniform magnetic field, which can accelerate a magnetic component in practical applications such as electric bells and loudspeakers. Inside the solenoid, the magnetic field is approximately uniform and parallel to the axis, while it is negligible outside. Ampere's law, given by $Bx=\mu_0 \frac{Nx}{L} i \rightarrow B=\frac{\mu_0 N}{L} i$, is recommended for this approximation (Beléndez & Beléndez, 2002; Haider et al., 2019). A rotating solenoid, a variant with distinct properties valuable in science and engineering, offers key functionalities, these include the winding density of copper coils, which facilitates the conversion of electrical current into mechanical motion, and the development of magnetic forces resulting from the movement of electric charges within the solenoid (Pesoa et al., 2011; Moser , 2021; Nosu et al., 2017).

A toroid is a hollow circular structure densely wrapped with enameled coils, leaving no gaps between them. When higher inductance is required at lower frequencies, a toroidal coil functions as a circular solenoid and is commonly used as an inductor in circuits. It is a coil of enameled wire wrapped around a crushed iron doughnut shape. Toroidal applications include low-frequency inductors, power generators, and low-frequency transformers (Correa et al.,2020; Savkovic et al., 2017), (Madinabeitia, 2014; Nosu et al., 2017), (Gomis, 2011) and (Oré, 2007; Tanaka et al., 2017).

Research method using GeoGebra and JavaScript

The methodology used to develop the simulation of electromagnetic fields in solenoids and toroids will be carried out using the programming language JavaScript, applied in the virtual simulation software GeoGebra in such a way that the modeling and control of parameters was combined due to the visual resources of GeoGebra and the resources of control and establishment of values that allows us to stablish JavaScript to create simulations as real as if they were made manually, somehow to achieve concatenate the experience of the simulation of such an important subject of Physics II, such as Solenoids and Toroids. This is how (Zambrano & Zambrano, 2019) mention that mathematics and physics are real importance subjects, in which it is possible to know the world, explain it and make decisions. One of the best simulation tools is GeoGebra software, which is considered an educational tool that provides the ability to transform the traditional environment of the educational system into an interactive space that leads to deep learning in mathematics and in the development of skills that allow learning with purpose. That is why it is understood that in particular, technological products have influenced the way of learning and teaching science, somehow it is possible to visualize, organize and analyze data, offering various resources and tools that enhance the discipline, real cases of its application are presented, in this research work it was developed the simulation of valves and transformers, applying JavaScript in conjunction with GeoGebra to see the reaction of the change of parameters in both the solenoid closed valve and the toroidal transformer which allowed us to show the importance of the potential to develop a virtual modeling, allowing students to learn the subject of virtual electromotive force (emf) using diverse laws that can help us to execute this modeling. Also, it will be proved that the management of this educational application is given in various areas of physics, thus generating good academic performance.

Results

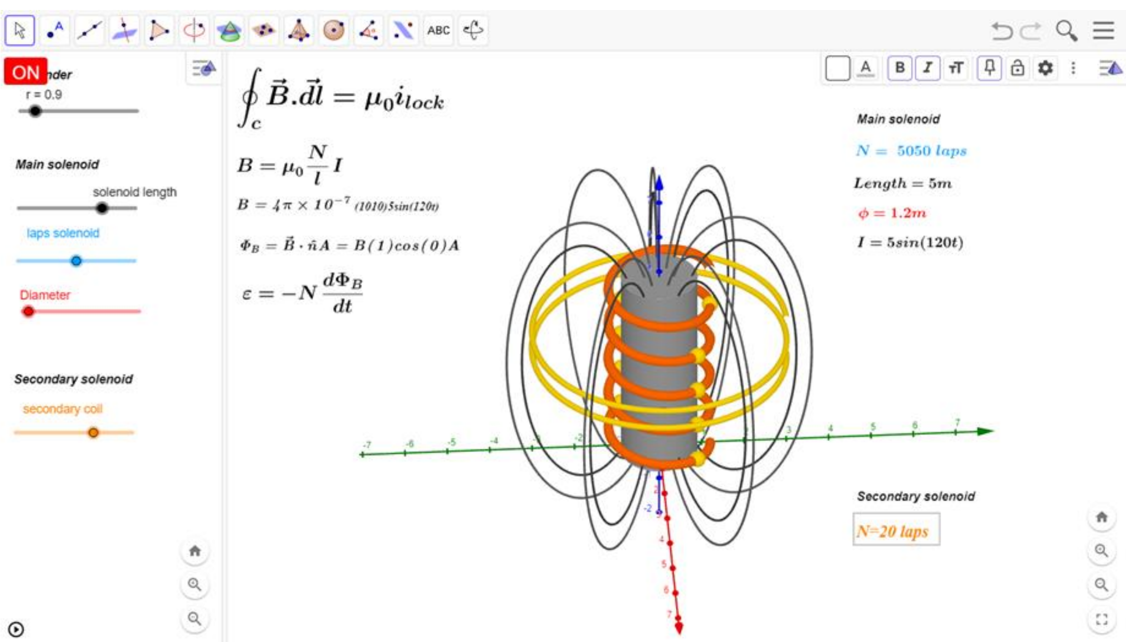
Simulation of GeoGebra

Now the results of the research will be presented, for this, the simulation is performed in the GeoGebra application which in turn is linked to JavaScript programming language, this will allow to develop the simulation of solenoids and toroids, magnetic field lines generated by an electromotive force (emf) and their applications in real environments such as solenoid valves or toroidal transformers.

Modeling 1: Solenoid valve (integration with JavaScript language)

Image 1:

Solenoid valve



The image represents the simulation of a solenoid valve introduced by a magnetic field

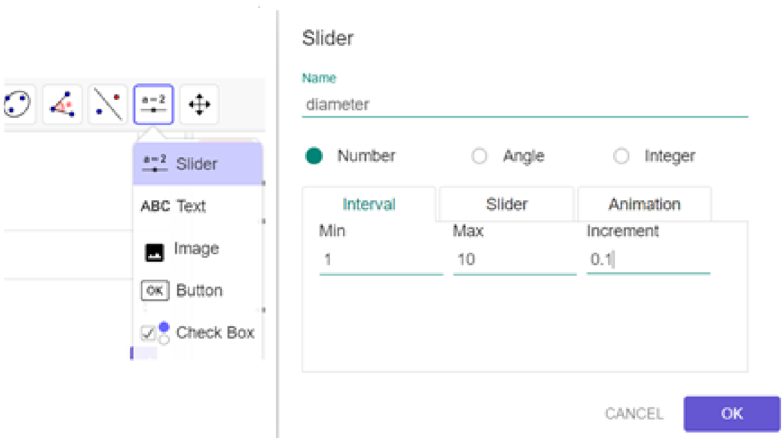
Step 1: defining initial variables

The initial variables to be used in the construction of the solenoid valves are defined as follow:

diameter=1,length=5, number_laps=500 y cylinder_radius=0.9. These variables are linked to sliders to allow real-time adjustments. To add a slider in GeoGebra, navigate to the Slider option, assign a name, and specify its initial value, final value, and increment.

Image 2:

Slider in GeoGebra



The image illustrates the procedure for adding sliders in GeoGebra.

Step 2: Plotting the Solenoid:

To graph the primary solenoid in a three-dimensional plane, parametric curves must be used. This involves defining three functions that depend on the variable t, as follows:

$$f(t) = diameter\ sin(t)$$
$$g(t) = diameter\ cos\ cos\ (t)$$
$$h(t) = \frac{1}{2\pi} t$$

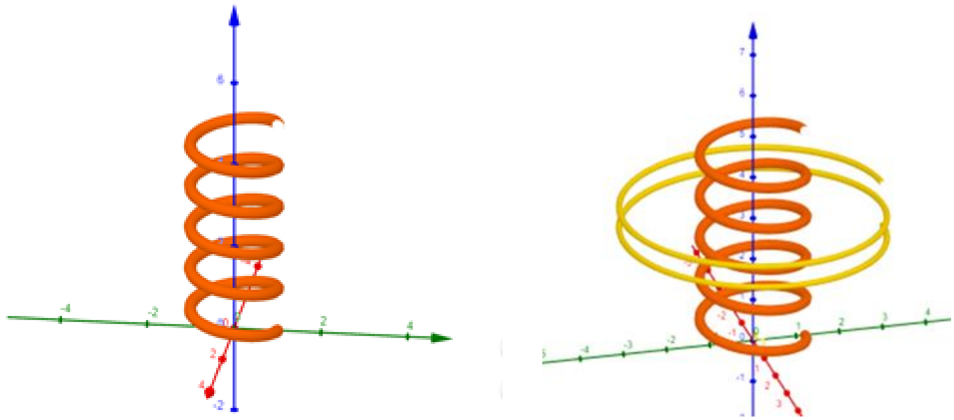
Then, the curve command that integrates GeoGebra is used to make the graph based on a parametric curve. The applied command is as follows:

$$a = Curve(f(t), g(t), h(t), t, 0, 10\pi)$$

The values 0,10π are assigned to the variable t, defining the range over which the solenoid will be plotted.

Image 3:

Primary and secondary solenoid.



The image represents solenoids in three dimensions in GeoGebra.

The procedure is like plotting the secondary solenoid, where functions are defined and associated to the Curve command in GeoGebra.

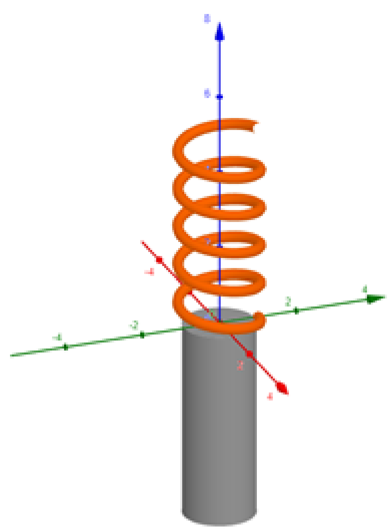
Step 3: Plotting a Cylinder (represents the valve needle or stem)

To graph a cylinder in a three-dimensional plane, first define the variable p, which will control the cylinder's movement. Next, define two points: $A = (0,\ 0,\ p)$ and $B = (0, 0,\ p + 5)$. The cylinder is then plotted using the following command:

$$Cylinder(A, B,\ cylinder_{radius})$$

Image 4:

Solenoid valve iron stem or core.



The image represents the solenoid valve stem to be induced by an electromagnetic field.

Step 4: Plotting the magnetic field lines:

It should be worked with parametric curves, defining three functions that depend on the variable t, as follows:

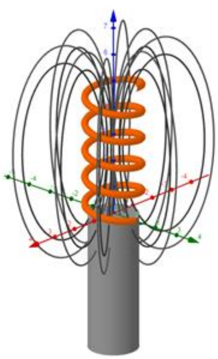
$$i(t) = cos(t)C_1 + C_2$$
$$j(t) = 0$$
$$k(t) = diameter(C_3\ sin\ sin\ (t)\ +\ C_3)$$

The variables C_1, C_2 and C_3 are used to define the size and position of the field lines in the Cartesian plane.
Then, the curve command that integrates GeoGebra is used to plot the graph based on a parametric curve. Any of the following commands can be used to plot the field line:

$$b = Curve(i(t), j(t), k(t), t, -\pi, \pi)$$

$$b = Curve(cos(t)C_1 + C_2, 0, diameter(C_3\ sin\ sin\ (t)\ +\ C_3),\ t, -\pi, \pi)$$

The values of $-\pi,\ \pi$ are assigned to the variable t, defining the range over which the field line will be plotted.
Using the same approach for plotting a field line, other lines can be plotted by adjusting the values of t, C_1, C_2 and C_3 or even replacing these variables with others. This allows for the representation of different magnetic field lines at various points in space with different magnitudes.
Image 5:
Magnetic field lines.



The image represents the field lines induced by an electromotive force (emf).

Step 5: Defining the magnetic field parameters:
The magnitude of the magnetic field is defined as a function of time, for this, an intensity function such as $5sin\ (120t)$ is used as an example.
The purpose of the magnetic field is to attract the cylinder (iron rod or core) and, likewise, generate an induced electromotive force (emf) in the secondary coiled. The following function is then defined in GeoGebra.

$$B_m(t) = 4\pi \times 10^{-7} \frac{number_{laps}}{length} 5sin\ (120t)$$

This entered command represents the formula to find the magnitude of the magnetic field in the solenoid, which is:

$$B = \frac{\mu_0\ N\ i_{lock}}{l}$$

Now, the magnetic field flux is also defined as a function of time to later obtain the induced electromotive force (emf). The following command is entered in GeoGebra:

$$\Phi_B(t) = B_m(t)\frac{\pi D^2}{4}$$

This command represents the formula to calculate the magnetic field flux in a solenoid, which is:

$$\Phi_B = \vec{B}.\hat{n}A$$

Finally, the induced electromotive force (emf) in the secondary solenoid is obtained through the following function in GeoGebra:

$$fem(t) = -number_{laps}\ Derivate(\Phi_B)$$

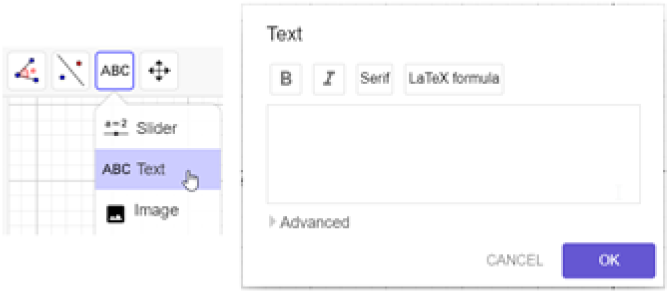
This command represents the formula for the electromotive force (emf) induced by a solenoid, which is:

$$\varepsilon = -N\frac{d\Phi_B}{dt}$$

The Derivate command is used since the formula requires the derivative of the magnetic flux.

Step 6: Values represented:
Values will be represented through the text tool, to do this, select the text tool and assign the corresponding values.

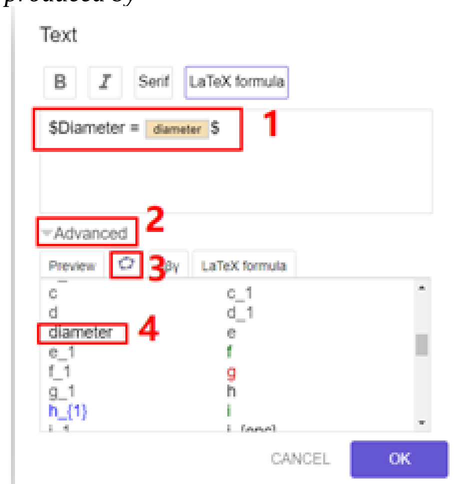
Image 6:
Text insertion



The image represents the procedure for text insertion in GeoGebra.

To associate variables with text, follow the steps shown in the image below.

Image 7:
Text insertion



The image shows the procedure for associating the defined variables with the text.

In this way, multiple texts are generated, representing the values obtained during the simulation process.

Additionally, the values are linked to the GeoGebra spreadsheet based on functions defined to calculate the magnitude of the field, flux, and induced emf.

Image 8:

GeoGebra Spreadsheet

	C	D	E
5	$4\pi \cdot 10^{-7} \cdot 1010 \cdot 5 \sin(120\,t)\, \frac{\pi}{4} \cdot 1.2^2$	$\frac{3}{50000} \cdot 1.2^2 \cdot 1010\, \pi^2 \cos(120\,t)$	$-20 \cdot \frac{3}{50000} \cdot 1.2^2 \cdot 1010\, \pi^2 \cos(120\,t)$
6	0	0.861	-17.225V
7	0.004	0.701	-14.024V
8	0.007	0.281	-5.612V
9	0.007	-0.244	4.887V
10	0.004	-0.678	13.569V
11	0	-0.86	17.208V
12	-0.004	-0.723	14.453V
13	-0.007	-0.316	6.326V
14	-0.007	0.208	-4.152V
15	-0.005	0.654	-13.087V
16	-0.001	0.858	-17.158V
17	0.004	0.743	-14.853V
18	0.007	0.351	-7.027V
19	0.007	-0.17	3.409V
20	0.005	-0.629	12.579V
21	0.001	-0.854	17.074V
22	-0.003	-0.761	15.224V
23	-0.006	-0.386	7.715V
24	-0.007	0.133	-2.66V
25	-0.005	0.602	-12.047V
26	-0.001	0.848	-16.957V
27			
28			

The image represents the processed functions over time in the GeoGebra Spreadsheet.

Step 6: Integrating with JavaScript

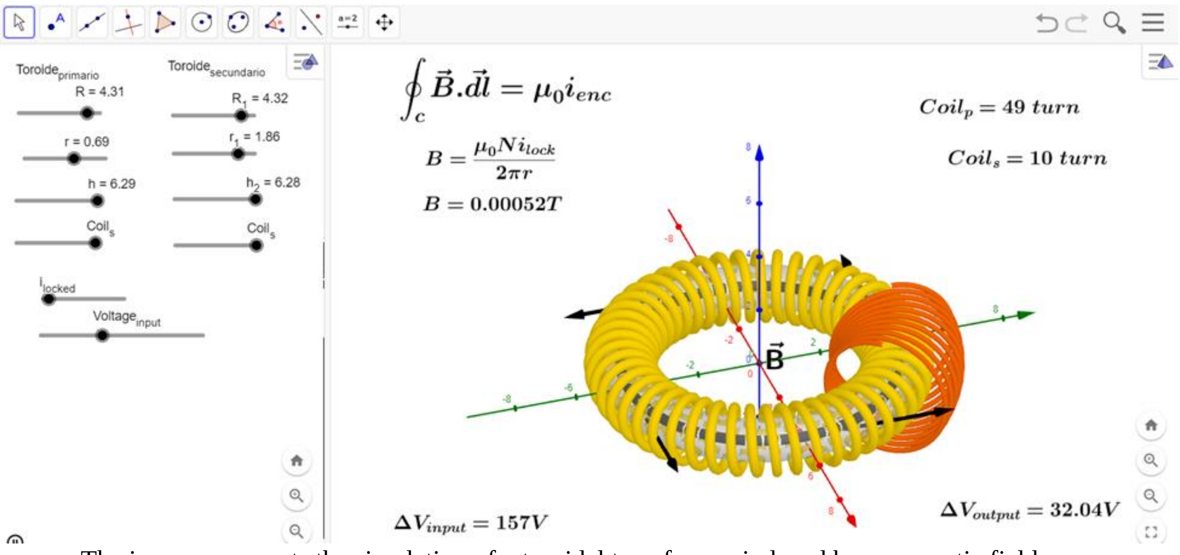
The integration with JavaScript aims to simulate the appearance of an electromagnetic field when a button is pressed. As a result, the cylinder (representing the valve needle or stem) will move. This causes the stem to be attracted by the field lines generated when the electric circuit is activated. The programming involves animating the variable defined during the cylinder construction process. This variable will change its value, causing the cylinder to move accordingly. Additionally, through JavaScript programming, electrons are generated within the solenoid, and their animation is displayed.

Programming codes used to simulate the solenoid valve

ggbApplet.evalCommand: Evaluate the given string as if it were entered in the GeoGebra input bar. Returns whether the command execution was successful.
ggbApplet.getXcoord: Returns the Cartesian X-coordinate of the object with the specified name.
ggbApplet.getYcoord: Returns the Cartesian Y-coordinate of the object with the specified name.
ggbApplet.setPointSize: Sets the size of a point (range: 1 to 9).
ggbApplet.setColor: Sets the color of the object with the specified name.
ggbApplet.setAnimating: Defines whether an object should be animated.
ggbApplet.startAnimation: Starts automatic animation for all objects with the animation flag set.
ggbApplet.stopAnimation: Stops the automatic animation for all objects with the animation flag set.
ggbApplet.deleteObject: Deletes the object with the specified name.

Modeling 2: Toroidal transformer
Image 9:

Toroidal transformer



The image represents the simulation of a toroidal transformer induced by a magnetic field.

Step 1: Defining Initial Variables

The initial variables for constructing the toroidal transformer are defined as follows: $R = 4, ncoil_p = 50$ and $ncoil_s = 10$. These variables are linked to sliders, allowing for real-time adjustments. The procedure for adding sliders and associating them with variables is explained in Modeling 1.

Step 2: Plotting the Primary Toroidal Coil

To graph the solenoid in a three-dimensional plane, parametric curves must be used. This involves defining three functions that depend on the variable t, as follows:

$$f(t) = \left(R + sin\, sin\, \left(ncoil_p t\right)\right) cos\,(t)$$
$$g(t) = \left(R + sin\, sin\, \left(ncoil_p t\right)\right) sin\,(t)$$
$$h(t) = cos\,(ncoil_p t)$$

Next, the curve command in GeoGebra is used to generate the graphic based on a parametric curve. The applied command is as follows:

$$a = Curve(f(t), g(t), h(t), t, 0, 2\pi)$$

Then, a toroidal surface is plotted to represent the iron core wrapped by the coil, which will induce an electric current in a secondary winding. To achieve this, parametric curves are used by defining three functions that depend on the variable t, as follows:

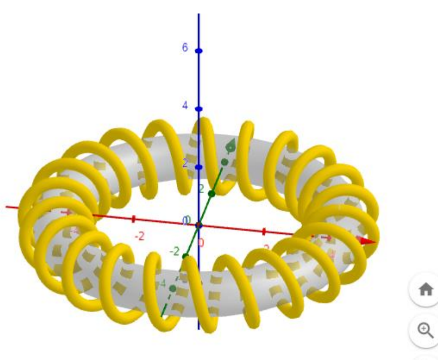
$$sf(u, v) = (R + r\, cos\, cos\, (u)\,)\, cos\, cos\, (v)$$
$$sg(u, v) = (R + r\, cos\, cos\, (u)\,)\, cos\, cos\, (v)$$
$$sh(u) = r\, sin\,(u)$$

Next, the surface command in GeoGebra is applied to generate the graphic based on the functions sf, sg, sh. The applied command is as follows:

$$Surface(Sf(u, v), sg(u, v), sh(u), u, 0, 2\pi, 0, 2\pi)$$

Image 10:

Toroidal surface



The image represents a winding around an iron core (toroidal surface).

Step 2: Plotting the Magnetic Field Lines

To plot the magnetic field lines, parametric curves must be used, defining three functions that depend on the variable t, as follows:

$$i(t) = R\, sin\,(2t)$$

$$j(t) = R\, cos\, cos\, (2t)$$
$$k(t) = 0$$

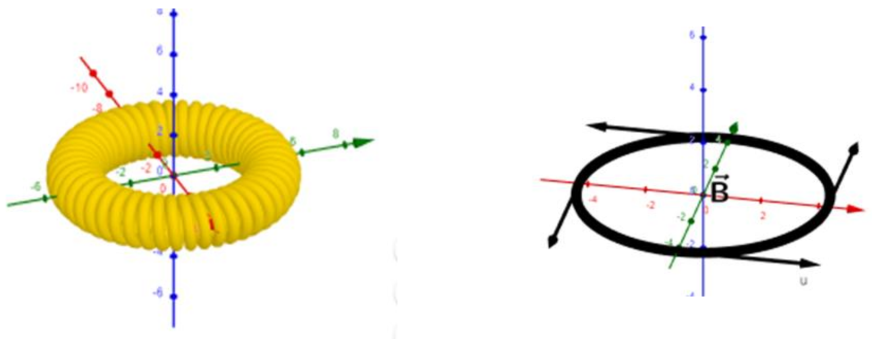
Next, the curve command in GeoGebra is used to generate the graphic based on parametric curve:

$$b = Curve(i(t), j(t), k(t), t, 0, 2\pi)$$

Simultaneously, tangential vectors are added to the curve. To define a vector, the points $A = (0, R, 0)$ and $B = (5, R, 0)$, are established, and then the following command is entered: $vector(A, B)$. To plot additional vectors, the procedure remains the same.

Image 11:

Magnetic field of a toroid



The image represents the toroid induced by an emf and the magnetic field lines generated.

Step 3: Obtaining the magnetic field

To obtain the magnetic field of simulation, the following command is entered in GeoGebra.

$$B = \frac{(4\pi \times 10^{-7})(ncoil_p)(intensity)}{2\pi R}$$

The entered command represents the formula for calculating the magnetic field in a solenoid, which is:

$$B = \frac{\mu_0\, N\, i_{lock}}{2\pi R}$$

Step 4: Plotting the Secondary Toroidal Coil

To plot the solenoid in a three-dimensional plane, parametric curves must be used by defining three functions that depend on the variable t, as follows:

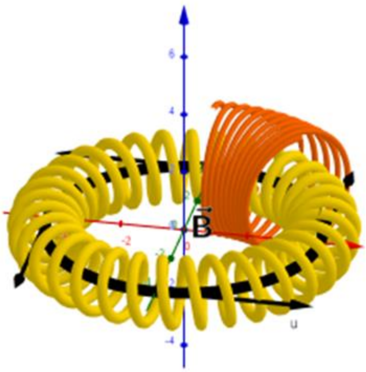
$$l(t) = \left(R + sin\, sin\, \left(ncoil_p C_1 t\right) C_2\right) cos\, (t)$$
$$m(t) = \left(R + sin\, sin\, \left(ncoil_p C_1 t\right) C_2\right) sin\, (t)$$
$$n(t) = cos\, (ncoil_p C_1 t) C_2$$

Next, the curve command in GeoGebra is applied to generate the graphic based on these parametric equations. The command used is:

$$d = Curve(f(t), g(t), h(t), t, 0, 2\pi)$$

Image 12:

Primary and secondary coil



The image represents the toroidal transformer induced by two coils, illustrating the relationship between the number of turns.

Step 5: Calculating the Voltage of a Transformer via the Secondary Toroidal Coil

To determine the output voltage of the toroidal transformer, the relationship between the number of turns in the primary toroidal coil (ncoil_p) and the number of turns in the secondary toroidal coil (ncoil_s) must be considered. For this purpose, a new variable is introduced, which will be used to obtain the output voltage using the following command in GeoGebra:

$$voltage_{output} = \frac{ncoil_p}{ncoil_s} voltage_{input}$$

This equation simulates the operation of a toroidal transformer.

Discussion

Education is an indispensable part of new technologies, playing a crucial role as many universities worldwide require knowledge in technological fields as a prerequisite for exams. Its approach and dedication are fundamental objectives in preparing future digital experts in the workplaces. Therefore, in recent years, the concept and application of computing have become highly relevant, particularly in methodologies that incorporate simulation software to support learning and problem-solving. Computer software packages enable users to explore and analyze potential applications, understand their relevance, and connect them to virtual-world solutions for effective problem resolution. In fact, as with programming, the content can be complex and extensive due to decades of continuous development and innovation. According to Tennuto (2003), it is essential to understand how to achieve, explain, and create a completely new educational space where innovation and technology go hand in hand, shaping the evolution of educational strategies through the implementation of these new technologies. However, some authors, such as (Narvarte, 2008; Tesprasit et al., 2023), argue that face-to-face, school-based education is effective not only in terms of verbal expressions but also in enabling full recognition of emotions, doubts, and responses. In fully in-person learning environments, students tend to engage more attentively. Therefore, it emphasizes that in the new virtual environment, this type of learning is not fully achieved, as it takes place in an artificial setting, making it more challenging.

Likewise, Perez & Pellicer (2011) state that the study of solenoids is currently considered highly significant due to their increasing importance and relevance in the application of mathematics to dynamic systems, particularly in analyzing solenoid-based actuators. This highlights the critical nature of the work being conducted, as solenoids play a fundamental role in physics and its various applications, warranting greater attention in the field.

Similarly, Herrera (2016) states that toroids play a crucial role in telecommunications, as they enable the diversification of various parabolic antenna models, consequently their application is expected to enhance our understanding of telecommunications. Given their significance in interconnectivity, toroid should be regarded as essential in physics, therefore, this study is supported by its innovative approach, providing a practical explanation of the operation of both solenoids and toroids in real-world applications.

This study effectively demonstrates how solenoids and toroids interact, considering each parameter without variation, whether within the framework of "new virtual reality" or, in some cases, as a purely theoretical construct. It has been proven that virtual simulations can be highly accurate, often exhibiting an even smaller margin of error and closer approximation to real-world conditions.

Conclusion

The use of new technologies helps to reduce costs in research and modeling, as seen in the case of applied solenoids and toroids. Before making financial investments, companies prefer to conduct simulations of new scenarios based on established physics theories and technological innovations. Additionally, magnetic fields play a fundamental role across various fields of science and engineering.

The first objective is to determine whether students can visualize and understand the behavior of the magnetic field. By the end of the simulation, the graphical and dynamic representation allows students to observe the magnetic field lines and their intensity when an electric current is induced, depending on the number of turns in the toroid.

The second objective is about the possibility for the student to experiment with different parameters in GeoGebra's dynamic worksheet without the need for a physical laboratory to understand the phenomenon of the magnetic field. In conclusion, the simulation allows modifications to the number of turns and the diameter of both the toroid and solenoid, helping the student understand that the magnetic field remains dependent on the geometric shape and the permeability of the magnetic material.

The third objective is for the student to develop modeling and simulation skills using Ampere's law, the Biot-Savart law, and other physics equations related to the magnetic field. Students and researchers can perform modeling through mathematical equations, which are then applied to computational simulations using various tools. In this case, GeoGebra was used, a dynamic and versatile software suitable for programming-level applications.

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