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Original

ANIMATION OF PLANE ELECTROMAGNETIC WAVES IN VACUUM USING WINPLOT SOFTWARE: A TEACHING EXPERIENCE

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ABSTRACT

In this work, the Winplot software was used to animate plane electromagnetic waves in a vacuum. The target audience was a class of 18 undergraduates in Physics and was applied at the Federal University of Acre, campus Rio Branco, in Brazil. The activity was carried out in a computer lab and conducted through a script with detailed instructions. The results were satisfactory, where participants got more than 60.0% right of four of the six investigative questions. In evaluating the activity, 88.9% considered it a good method to visualize the propagation of electromagnetic waves and 77.0% classified the activity as excellent or good. The application of the activity allowed a dynamic view of the propagation of plane electromagnetic waves in a vacuum, which could contribute to the teaching of such content.

Keywords: Winplot. Simulation of the propagation of electromagnetic waves. Physics education. Animati on of math functions.

INTRODUCTION

The simulation of experiments and phenomena is an important didactic resource in science teaching and one of the most outstanding is PhET (Physics Education Technology) Interactive Simulations (1). It works in the areas of Physics, Chemistry, Mathematics, Earth Sciences and Biology and has more than 80 interactive simulations and games. PhET has more than 120 million simulations per year in over 200 countries, and more than 60% of these simulations took place in the United States (2). An application of PhET, through a didactic sequence, for enabling people for teaching Physics aimed at higher education and which could be adapted for high school, was the work of Hadad, Melo Junior e Silva (3). O PhET provides user interaction through the study of phenomena with ready-made simulations.

Winplot (4) is a free software especially useful for making graphics in two and three dimensions, besides being able to generate animations. Richard Parris, Professor of Mathematics at the Philips Exeter Academy (Exeter, New Hampshire, United States), created Winplot, around 1985, using the C language. It was initially called PLOT and ran under the old DOS (Disk Operating System). With the release of Windows 3.1 in 1992, the program was renamed Winplot. In 2001 a version was created to run on Windows 98 using the C++ language (5). The download version is v 1.41 and was compiled on March 9, 2011, compatible with Windows 95/98/ME/2K/XP/Vista/7, but also runs on Windows 10.

Winplot allows users to create their own graphics and animations, encouraging creativity, in which case it could be considered an advantage over PhET.

Wolfram Mathematica (6) is a software that in its version 12 has more than 6000 functions, allowing to carry out investigations and simulations in the field of exact sciences. GeoGebra (7) is a free dynamic math software, easy to use, containing geometry, algebra, spreadsheets, graphs, and calculus, where one can make animations. Winplot represents a good alternative to Mathematica and Geogebra. Mathematica is paid software and Geogebra requires the user to have solid knowledge of functions to generate animations.

There are several works, aimed at teaching, that used Winplot. Chung (8) showed the relationship between an atomic orbital and the corresponding wave function of a hydrogen-like atom. Santos and Macêdo (9) proposed the study of transcendental functions for students in Mathematics and Physics, together with

Geogebra. Marinho (10) created a method for studying the quadratic function.

In the present work, Winplot was used in the construction of the animation of electromagnetic waves, based on the sine function, and intended to a Physics undergraduate class.

MATERIAL AND METHODS

The work was applied to a group of 18 students from the Physics course at the Federal University of Acre in Brazil (UFAC), Rio Branco campus, on October 28, 2019. The subject is called General Physics IV and is of an experimental nature. In this subject, the predicted contents are magnetic properties of matter, electromagnetic oscillations, alternating current, Maxwell's equations, electromagnetic waves, geometric optics, interference, diffraction, and polarization.

The class was held in a UFAC computer lab and lasted 100 minutes. The activity was developed through a script, whose title was "Application of the Winplot software in the animation of the propagation of plane electromagnetic waves".

The class started with a brief explanation about its purpose and then the scripts were delivered, where each student used a computer to do the activities. During the execution of what was proposed, students called the class supervisor as they encountered difficulties, however there were also many interactions between students.

The script applied contained 13 questions (Table 1), among orientations and activities, that the student should do to reach the final objective, that is, the simulation of the propagation of electromagnetic waves, in addition to initial instructions for downloading and installing the software.

Table 1 - Questions 1 to 13 of the script. Source: the authors.

Installing and running Winplot	
I. Access https://softfamous.com/winplot/ II. Click Free Download and then Download. III. Save the wp32z.exe file. IV. Open the Downloads folder and click wp32z.exe file. V. Click Unzip and then OK. VI. Open folder C, click peanut and then winplot. **Note**: Winplot tends to crash, especially after using the command that generates functions animation, so it is advisable to save the files after entering the data. To save click on **File → Save or Save as...**	
Question	**Statement**
1	Click Windows → 2-dim. A page with the graph will open, press Equa → 1. Explict ... Type in f(x) = sin(x) and press ok.
2	Let us make an animation. Click on edit in the inventory window, change f(x) = 5sin(x+a) and then ok (we chose amplitude equal to five for easier visualization, feel free to change if you want). Activate Anim.→ Parameters A-W ... → autocyc. See the direction of wave propagation. Note that you can adjust: Q = quit, P = pause, F = fast, and S = slow.
3	Stop the animation by pressing Q. What should you do to change the wave propagation direction?
4	What is the physical meaning of “a” in the expression f(x) = 5sin(x+a)?
5	Try to make an animation with the formula used in item 1. Was it possible? Why?
6	Now we will perform the envelopes that represent the propagation of the fields, electric and magnetic, of a plane electromagnetic wave, using the function of question 4. Close the two-dimensional graph and click on Windows → 3-dim.

<table>
<tr><td>7</td><td>Click Equa → 2. Parametric ... A box will appear “surface x(t, u), y(t, u), z(t, u)” and complete the fields x, y, and z, according to the data of Surface 1 of Table S1. Repeat the initial command and fill in the data of Surface 2.

Table S1 - Surfaces of the envelopes that characterize the propagation of the electromagnetic wave.
<table>
<tr><th colspan="2">Surface 1</th><th colspan="2">Surface 2</th></tr>
<tr><td>x</td><td>t</td><td>x</td><td>t</td></tr>
<tr><td>y</td><td>5sin(t+a)</td><td>y</td><td>0</td></tr>
<tr><td>z</td><td>0</td><td>z</td><td>5sin(t+a)</td></tr>
</table></td></tr>
<tr><td>8</td><td>Insert the axes (View → Axes → Axes). Animate (Anim. → Parameters A-W ... → autocyc). On which axis and in which direction does the wave propagate?</td></tr>
<tr><td>9</td><td>The last stage of the simulation elaboration will consist in the insertion of the vectors, electric and magnetic fields, in the plane wave.</td></tr>
</table>

<table>
<tr><td>10</td><td>Click on Windows → 3-dim and press Equa → Segment ... A “segment from (a, b, c) to (d, e, f)” frame will appear. This means that you can construct a line segment that originates from the coordinates (a, b, c) or (x_1, y_1, z_1) and ends in (d, e, f) or (x_2, y_2, z_2). We will place the vector arrows by clicking p2 on arrows. Enter the coordinates of vector 1 (Table S2) and press ok, then give the initial command to place the data of vector 2, continue these steps until constructing vector 4. Run the animation.
Table S2 - Coordinates of the vectors associated with the electromagnetic wave.
<table>
<tr><th colspan="4">Vector 1</th></tr>
<tr><td>a</td><td>pi/2</td><td>d</td><td>pi/2</td></tr>
<tr><td>b</td><td>0</td><td>e</td><td>5sin(a+pi/2)</td></tr>
<tr><td>c</td><td>0</td><td>f</td><td>0</td></tr>
<tr><th colspan="4">Vector 2</th></tr>
<tr><td>a</td><td>pi/2</td><td>d</td><td>pi/2</td></tr>
<tr><td>b</td><td>0</td><td>e</td><td>0</td></tr>
<tr><td>c</td><td>0</td><td>f</td><td>5sin(a+pi/2)</td></tr>
<tr><th colspan="4">Vector 3</th></tr>
<tr><td>a</td><td>3pi/2</td><td>d</td><td>3pi/2</td></tr>
<tr><td>b</td><td>0</td><td>e</td><td>5sin(a+3pi/2)</td></tr>
<tr><td>c</td><td>0</td><td>f</td><td>0</td></tr>
<tr><th colspan="4">Vector 4</th></tr>
<tr><td>a</td><td>3pi/2</td><td>d</td><td>3pi/2</td></tr>
<tr><td>b</td><td>0</td><td>e</td><td>0</td></tr>
<tr><td>c</td><td>0</td><td>f</td><td>5sin(a+3pi/2)</td></tr>
</table></td></tr>
<tr><td>11</td><td>Explain why you assigned the value x = t in Table S1.</td></tr>
<tr><td>12</td><td>Why was assigned, in Table 1, y = 5sin(t+a) at z = 0 on Surface 1 and the opposite for variables y and z on Surface 2?</td></tr>
<tr><td>13</td><td>What is the reason for choosing pi/2 and 3pi/2 in Table S2?</td></tr>
</table>

RESULTS AND DISCUSSIONS

Initially, the students were asked to install Winplot on their computers, in some cases they needed the help of the supervisor, due to a lack of basic computer knowledge or because some computers had boot failures. In the last situation, the students were asked to use another machine.

Figure 1Figure 1 and Figure 2 show the images obtained after following questions 1 and 2, respectively (Table 1). The amplitude of the function in Figure 1 is 1 and it is static plot. In the amplitude is equal to 5 and the curve moves towards the negative direction of the X axis.

Figure 1 – Sinusoidal function f(x) = sin(x) plotted by Winplot. Source: the authors.

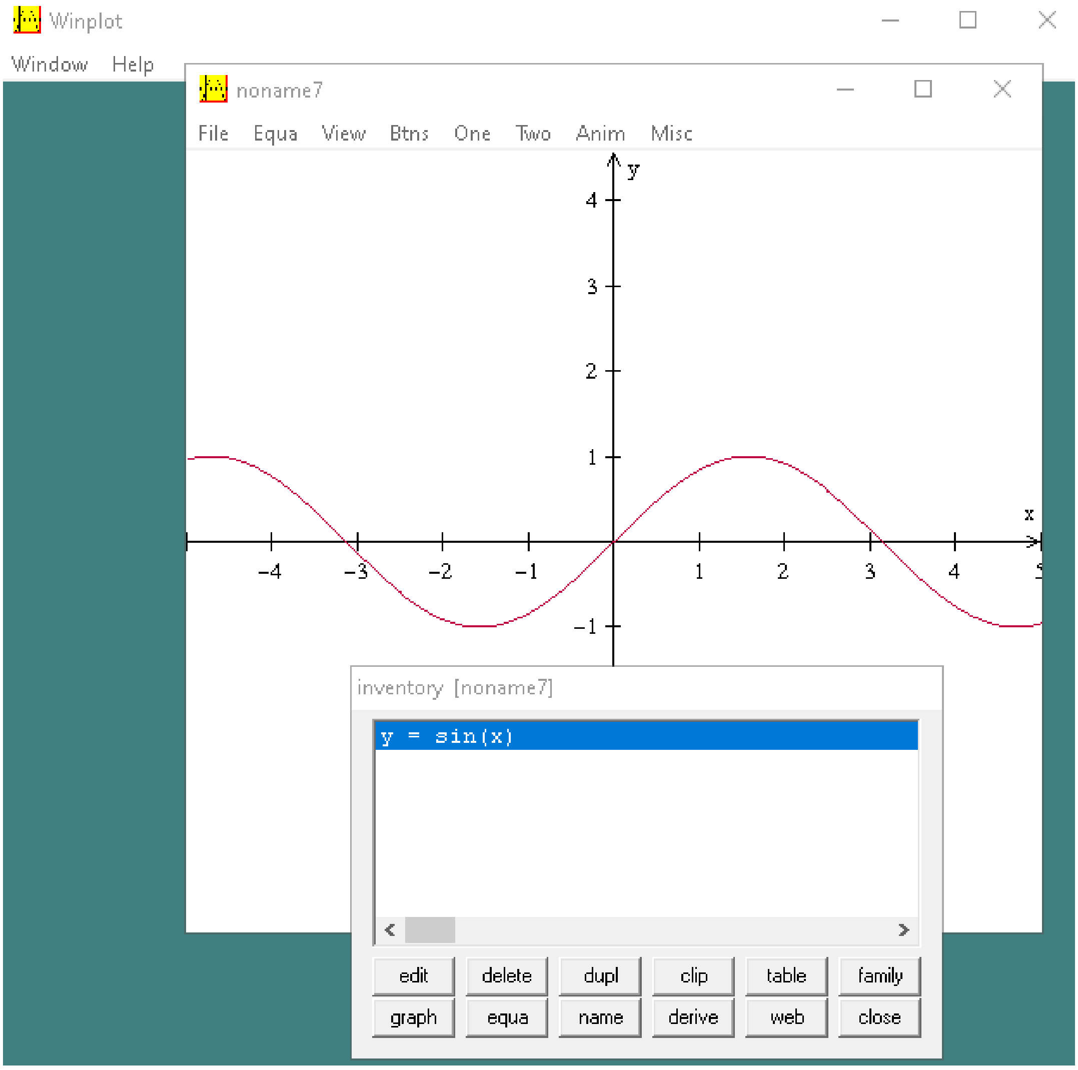
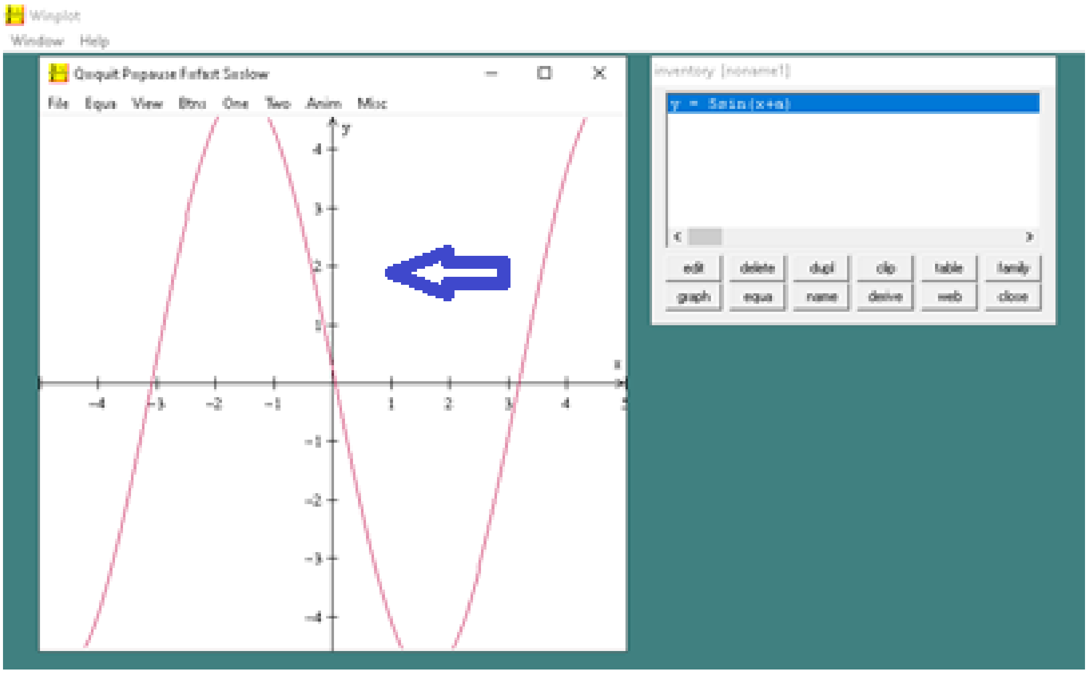


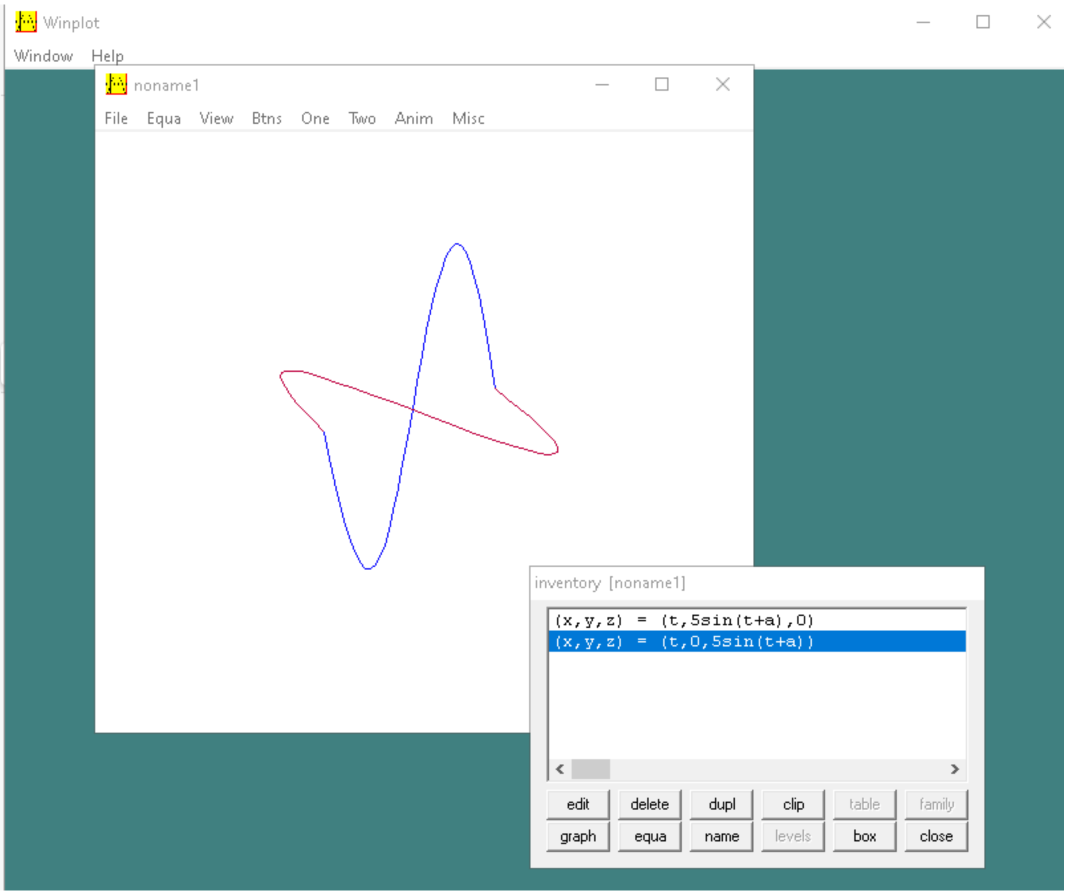
Figure 2 – Animation of the function f(x) = 5sin(x+a). The blue arrow has been inserted to indicate the wave propagation direction. Source: the authors.



In question 3 of Table 1, 16 students (88.9%) got the answer right, claiming that it would be enough to change the sign of the factor “a”. Fourteen participants (77.8%) answered question 4 correctly, saying that factor “a” was related to the direction of wave propagation. In question 5, 16 students (88.9%) observed that it was not possible to execute the animation when a = 0, due to the previous answer, and two did not provide a response.

After carrying out the orientations of questions 6 and 7 (Table 1), the students performed the animation that envelops the representation of the propagation of the fields, electric and magnetic, of an electromagnetic plane wave (Figure 3).

Figure 3 – Enveloping the propagation of electromagnetic waves. Source: the authors.



In question 8 of Table 1, the students could observe the propagation direction of the electromagnetic wave, going in the negative direction of the X axis (Figure 4).

Figure 4 – Image obtained in the animation after typing the commands in question 8. The red arrow has been inserted to indicate the wave propagation direction. Source: the authors.

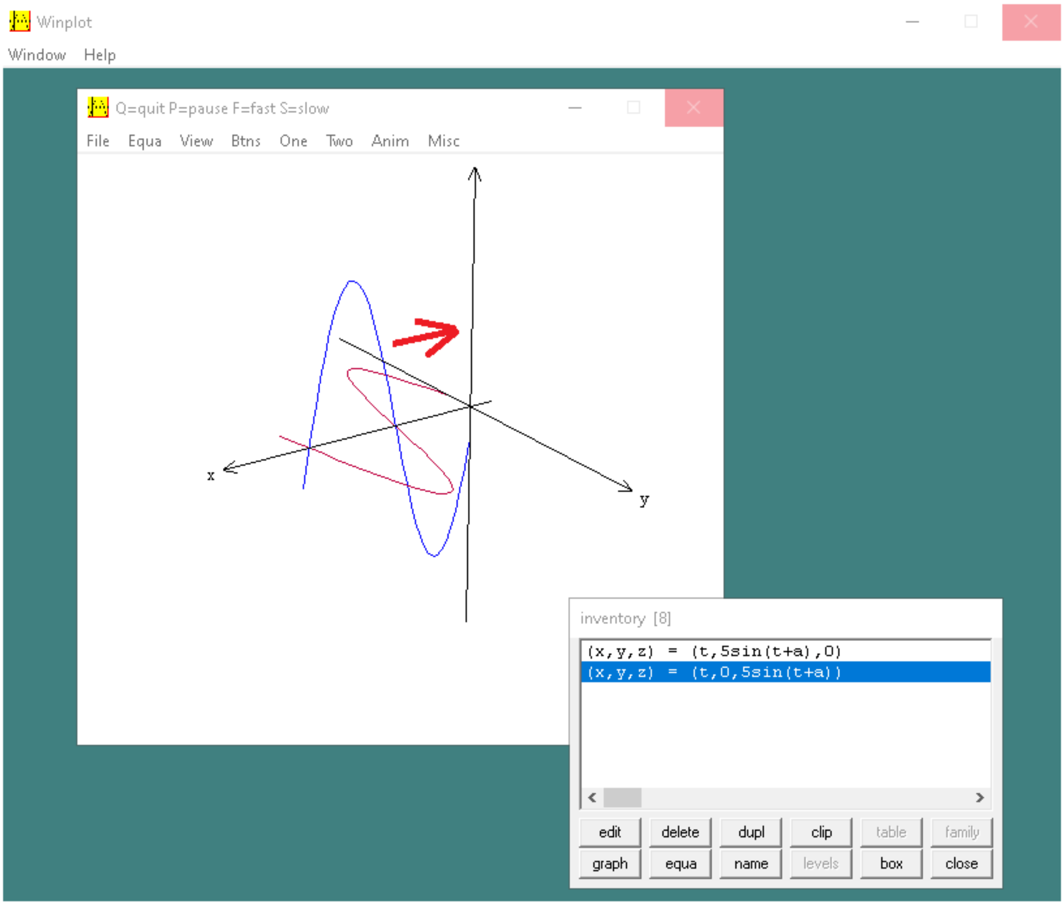


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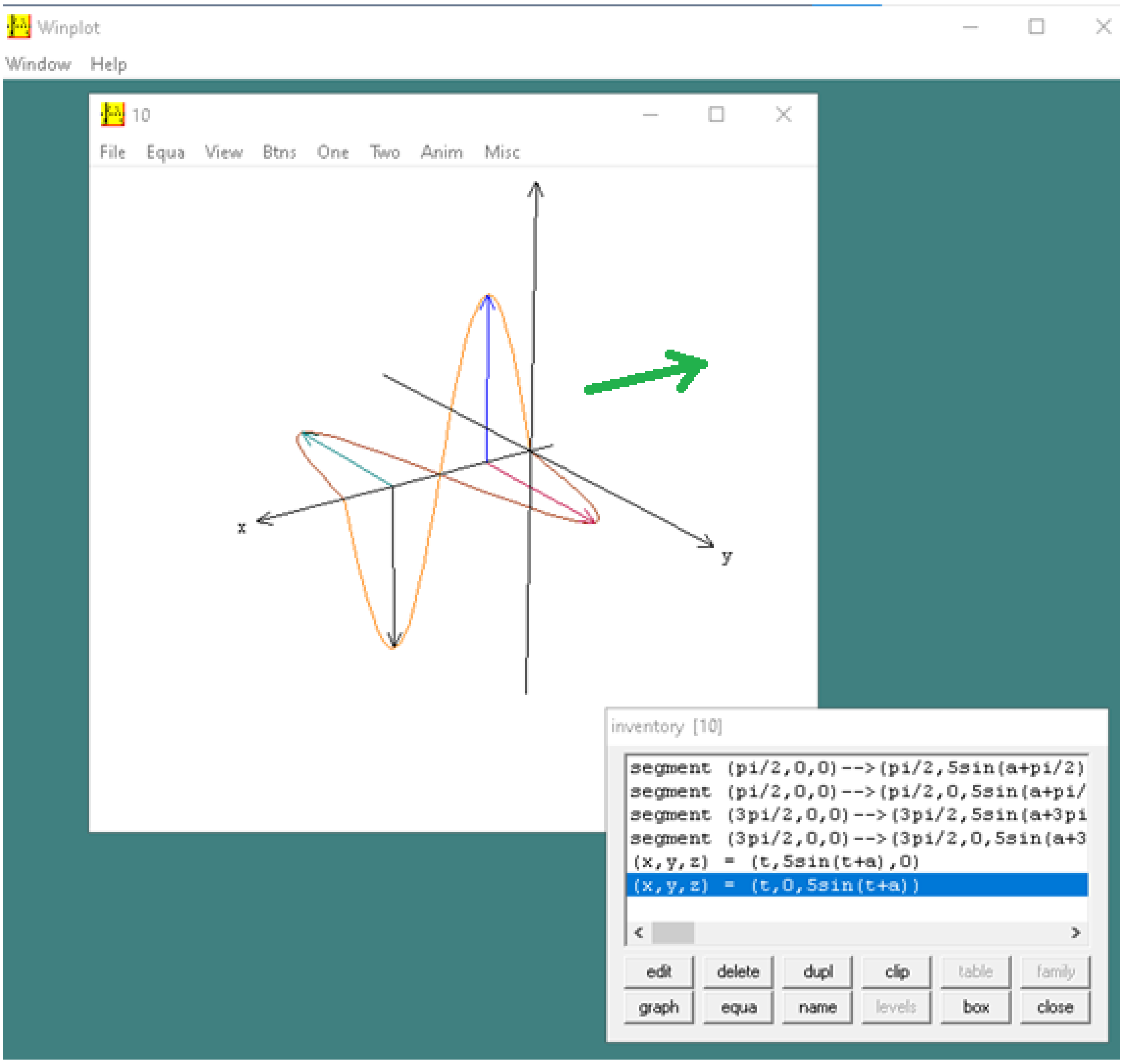
Figure 5 shows the last stage of the simulation (question 10 of Table 1), with the insertion of vectors of the electric and magnetic fields of the plane electromagnetic wave.

Figure 5 – Image from the animation after typing the commands in question 8. The red arrow was inserted to indicate the wave propagation direction. Source: the authors.



The value x = t on the two surfaces indicates that the x axis was chosen for the direction of wave propagation (question 11 of Table 1), however there were only 44.4% correct answers, the others answered that it was related to the period or propagation time.

The answer to question 12 of Table 1 was that the electric and magnetic fields, must be orthogonal, explaining the inversion of the data assigned to Y and Z of surfaces 1 and 2, with 55.5% of correct answers. A total of 61.1% of the students correctly explained question 13 (Table 1), that is, they recognized that these values were points of maximum and minimum amplitude.

A questionnaire was applied to evaluate the activity, containing 2 questions, see Table 2.

Table 2 - Script evaluation. Source: the authors.

Question	Statement
1	Do you think the activity contributes to the understanding and visualization of the propagation of plane electromagnetic waves?
2	Evaluate the activity by checking one of the options: ( ) Excellent ( ) Good ( ) Regular ( ) Bad

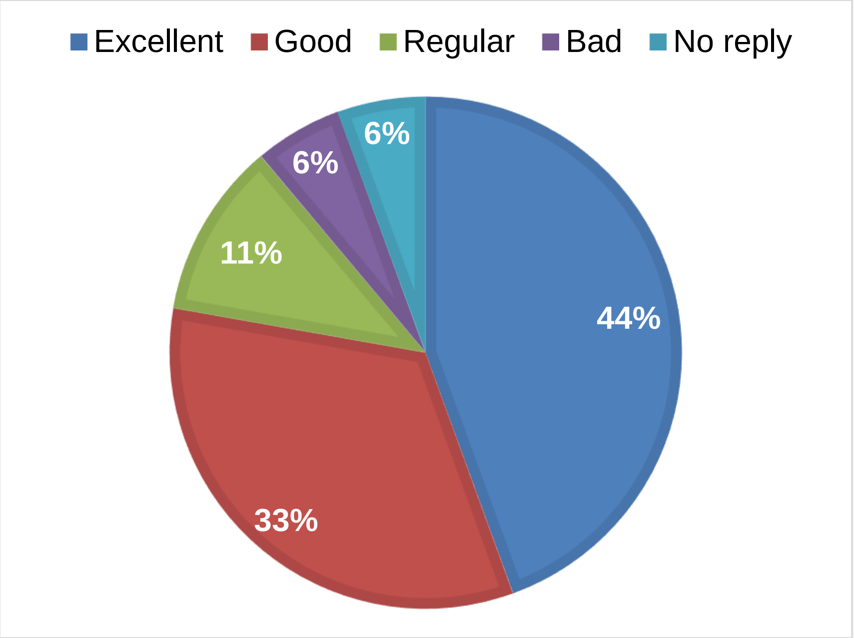
Table 3 shows the answers given by the participants regarding question 1 from Table 2. The majority (88.9%) liked the activity, claiming that it was a good method to observe the phenomenon, but there was a complaint that some computers and software were crashing. In fact, Winplot usually crashes when the command to generate the animation is called, a good way to minimize this, as was said in the initial instructions (Installing and running Winplot) of the script (Table 1), is to save the files, avoiding repeating data typing.

Table 3 - Answers assigned to question 1 of the script evaluation. Source: the authors.

Student	Answer
1	Yes, it is a good method of seeing how a wave behaves and how it propagates.
2	Yes, it is good to visualize the phenomenon.
3	Yes, the class represented the visualization of waves and we checked when it propagates, we also identified what it represents and its meaning.
4	I like it.
5	Yes, because by visualizing the phenomenon, understanding improves.
6	Yes, it made it easier to see the waves.
7	Yes, only theoretical classes make it difficult to visualize the propagation of waves.
8	Yes, but it would be nice to have better computers.
9	Yes, it facilitates the understanding of the mathematical part of the subject.
10	Yes, it allowed a review of the subject.
11	Yes, as it helped to see the interference of each variable.
12	Yes.
13	Yes, very good, as it exercises the practice of the theoretical subject.
14	I thought it was cool, I understood a little, it is good to visualize the waves, but it is necessary to know about electromagnetic waves to work with it.
15	Yes, I think it is great, as it allows for a better understanding of the content.
16	Yes.
17	In the case of visualizing an electromagnetic wave it helps, but it could be better represented on the blackboard, the commands should be simpler, and the program should crash less. This interferes a lot and when saved you cannot edit.
18	No reply.

Figure 6 shows a graph with the percentages given to each option. 77.0% liked the activity, 11.0% thought it was regular and only 6.0% (one person) did not like it, whereas 6.0% did not respond.

Figure 6 – Answers attributed to question 2 of the script evaluation. Source: the authors.



The class on the simulation of electromagnetic waves propagation was quite satisfactory, as it allowed the dynamic visualization of the phenomenon, providing a great advantage over static images shown in textbooks. Students developed computer skills when handling the software, in addition, the activity may encourage the development of new educational activities involving animations of other physical phenomena, such as the distribution of electric field lines in an electric dipole. Six questions in the script sought to investigate evidence of learning, having a good performance of correct answers, reaching more than 60.0% in four questions.

Of the three works mentioned in the introduction (8–10), only the one by Santos and Macêdo (9) was applied in the classroom with undergraduate students in Physics and Mathematics, using Winplot and Geogebra. In that work, it was noticed that, in the integration of the use of software in the treatment of transcendental functions, some students found it easy and others not so much. A similar fact was also verified in our work, however this fact did not hinder the development of the activity.

CONCLUSION

This work allowed physics students to observe the dynamic visualization of the propagation of plane waves in a vacuum, using Winplot software. Some students had difficulties installing the software and performing some steps of the proposed activities, but they were duly clarified by the supervisor or colleagues who had more facility.

The activity was conducted through a script that had the proper guidelines and six investigative questions. Most students considered the activity to be excellent or good and that it was a good way to observe the propagation of electromagnetic waves.

The application of the present work proved to be a viable alternative to improve the teaching the propagation of electromagnetic waves, which can be used both in high school and in higher education, as it allowed the simulation of the aforementioned phenomenon. No teaching papers with the content of our work were found, only in Mathematics and Quantum Mechanics, emphasizing the originality of our research.

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