Teaching Electromagnetism through a Transmission and Reception System of Electromagnetic Waves

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Abstract

The learning of phenomena related to electromagnetic waves develops in an evident way when students are stimulated significantly and, one of the possible ways are contextualized experimental practices. In this way, a system was developed that allows the sending and reception of electromagnetic waves, which can be provided by a signal generator or by a transmitting radio. For the implementation of the system, two Yagi-Uda antennas were built, intended for the transmission and reception of signals; for the emission of signals a low-power transmitter radio and for the measurement of the intensity of the received signals, a signal intensity meter was constructed from a multimeter in which a circuit was added that converts the signals received into direct current proportional to their intensity. The system was used in the physics discipline of high school, where it was observed that using this system, the students presented a better understanding of the phenomena related to electromagnetic waves.

Keywords: Antenna Yagi-Uda. Signal Intensity Meter. Electromagnetic waves. Physics teaching.

Introduction

Electromagnetic waves, present in people's daily lives, whether in radio, TV, cellular signals, among other devices can be generated, detected, as well as their characteristics being observed through appropriate devices.

Considering the importance of these electromagnetic waves, which are studied in the discipline of high school physics and that learning develops in a clear way when students are stimulated significantly and, that one of the possible ways are contextualized experimental practices, a system has developed that allows a better understanding of the wave phenomena involving these electromagnetic waves.

For the implementation of this system designated as transmission and reception system and electromagnetic waves, two Yagi-Uda antennas were built, intended for the transmission and reception of signals; for the emission of signals a low-power transmitting radio was used, in the UHF frequency range and; for the measurement of the intensity of the received signals, a signal intensity meter was constructed, from a multimeter in which a circuit was added that converts the signals received into direct current proportional to their intensity.

Antenna Considerations

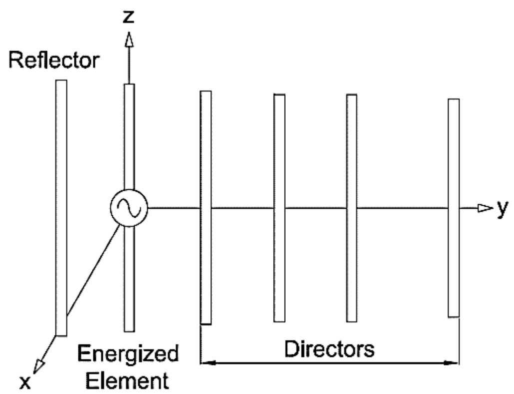
The antennas used in this system are the most important elements in this project, they transform electromagnetic energy guided by the transmission line into irradiated electromagnetic energy, and its physical dimensions are associated with the frequency of the signal to be transmitted or captured.

The efficiency of the built system depends on the performance of the radiant and receiving system; in this way, Yagi-Uda directional antennas were used. These antennas have radiation characteristics that concentrate radiated power in a given direction of space, covering a very restricted area, these characteristics are high directivity or gain, beam or angle of narrow half power and high front-back ratio.

Despite the simple appearance of the Yagi-Uda antenna, the design of this device is not an easy task, mainly because there are many interrelationships between the variables involved in the project, for example, the elements are electromagnetically coupled and a small variation in the length and/or spacing between the antenna elements can change the current distribution over all components (Farias *et. al.*, 2014).

A conventional Yagi-Uda antenna consists of parallel linear dipoles of which only one, usually the second element, is energized by a source, the remaining are parasitic elements. The first element acts as a reflector, which is larger in size than the energized element. From the third to the thon are master elements and are smaller than the source element. Figure 1 illustrates a Yagi-Uda antenna with six elements.

Figure 1 - Yagi-Uda antenna with six elements.



Source: Prepared by the authors (2021).

A good design of antennas considers the irradiation diagram and several parameters, such as: gain, directivity, aperture, polarization, front-back relationship, among other aspects. All these parameters are well known in the literature, however, to perform some tests and experiments it becomes interesting to model the antenna through simulation software, because it allows the variation of parameters for decision making.

One of the simulation software is the development by Makoto Mori, Alexander Schewelew and Igor Gontcharenko, which is available in basic and professional versions. This software is based on a NEC engine called MININEC-3, written in C++.

All data insertion is performed in a window only, separated by tabs called: geometry, visualization, calculation, and far field graph. On the geometry tab, the antenna is constructed using three-dimensional coordinates X, Y, Z. On this screen it is also possible to tell where the active dipole will be, what the voltage is inserted and the frequency (allowing input as wavelength). Once the data has been entered, on the preview screen you can see and spatially rotate the antenna, as well as select the elements of it.

On the calculation screen you can change the soil characteristics, change the operating frequency, select the diameter of the material, the type of material (copper, aluminum, iron, etc.). When adjusting, the "Start" button starts computing the data. The information is presented on the screen itself where it is possible to observe the ohmic resistance, impedance, the Ratio of Stationary Waves (SWR), the gain in dBi (isotropic decibels), the front-back ratio and the elevation of the antenna. On this screen there is the option to plot the graphics and collect more details of the projected antenna, such as: impedance, SWR, distant field and gain for arange of values, what the software calls "speculation".

Still on this screen it is possible to perform an optimization by inserting some objectives such as: achieving a certain SWR, front-back ratio, impedance, gain, etc. In the last guide, in the distant field charts, the horizontal, vertical irradiation profiles with various characteristics of the antenna are presented, it is also possible to obtain the 3D graph of the irradiation profile (Martins, 2016).

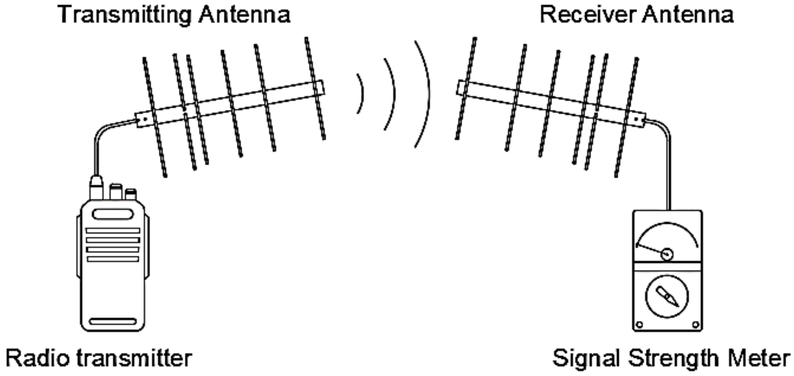
Among the available antenna modeling software, the MMANA-GAL (Mori; Schewelew; Gontcharenko, 2016). This software is based on NEC2 and NEC4 engines. The acronym for these engines stands for Numerical Electromagnetics Code, developed in the 1970s in Fortran by Gerald Burke and Andrew Poggio. These engines are used for antenna modeling, very popular by amateur radio amateurs, however they are not open source (Martins, 2016). The operation of NEC engines is described by the programmers themselves Burke, G.; Poggio, A. (1981). This code is based on the method of solving moments of the integral of the electric field by fine conductors and the integral equation of the magnetic field for conductive closed surfaces. It uses an interactive method to calculate the currents in a set of wires and the fields that result.

For receivers, the process begins by calculating the electric field in space by a radio signal of a given frequency along the X axis in three-dimensional space. This field is uniform in Y and Z but varies along the X axis; the magnitude of the signal at any point along X is defined by the phase at that instant. The antenna elements have different voltages at each point. What NEC does is break these elements into small, sampled points called "segments." The system uses simple calculations based on conductor diameter and signal wavelength to determine the voltage and induced currents in each of these segments, thereby enabling antenna modeling.

Material and Methods

The Transmission and Reception System d and Electromagnetic Waves proposed in this work is basically composed of two antennas, one transmitting and the other receiving, a radio transmitter and a signal intensity meter. His diagram is shown in Figure 2.

Figure 2 - Transmission and Reception System Diagram.



Source: Prepared by the authors (2021).

In this system used the Radio Transmitter Baofeng - Model BF-777S, as well as a programming cable of it. Figure 3 shows the Radio, Battery Charger, Baofeng accessories, and its programming cable.

Figure 3 - Radio Baofeng and accessories.

Source: Baofeng BF-777S (2019).

The transmitter radio was connected to the antenna by means of a coaxial cable, with UHF Macho connectors at its ends, in addition it was necessary to employ a Female SMA × UHF Female connector, to promote the conversion of the radio output, which features a Male SMA connector. Figure 4 shows the coaxial cable and Female SMA × UHF Female connector.

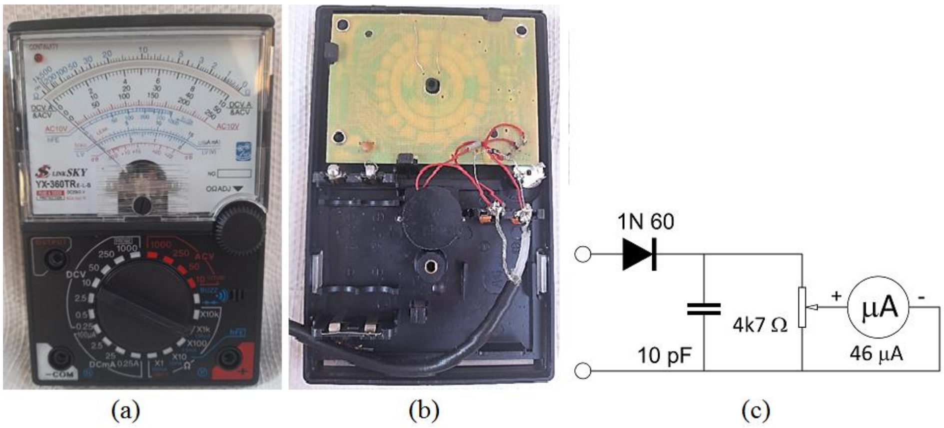
Figure 4 - Coaxial cable and SMA Female UHF Female connector.

Source: Prepared by the authors (2021).

The adjustment of the radio transmitter frequency was made through the CHIRP software, obtained on the development website, which is a free and open-source tool for programming radio transceivers transmitters of amateur radio (Smith, 2015).

The signal intensity meter was constructed from a multimeter, in which all its functions were disabled and, being the same disabled, a detector circuit was inserted, which was connected to the multimeter galvanometer. Figure 5 (a) shows the front; Figure 5 (b) shows the inside of the Signal Strength Meter and Figure 5 (c) shows the detector circuit.

Figure 5 - Signal Strength Meter.



Source: Prepared by the authors (2021).

The parameters of the 6-element Yagi-Uda antennas were obtained using the Mmana-Gal software, where the version used was basic 3.0.0.31 and the version's copyright is from 1999 to 2011. The main performance parameters of each 6-element Yagi-Uda antenna, designed for the operating frequency of 432.6 MHz were: Input impedance expressed in rectangular coordinates: R = 50.67 ohms, jX = −5,014 ohms; Stationary Wave Ratio (SWR) for transmission line of 50 ohms [SWR (50) = 1.11]; Gain relative to a dipole (Gh = 8.19 dBd); Ga absolute gain, i.e., relative to a radiator (Ga = 10.34 dBi); The gain ratio between the main lobe where the highest concentration of electromagnetic energy is, and the back lobe (opposite the main lobe), i.e., the front-coast relation (F/B = 18.1 dB). The term dBi represents the gain in dB relative to an isotropic antenna and the dBd represents the gain in dB relative to a half-wave dipole. The relationship is also: G(dBi) = G(dBd) + 2.15.

The data file for the 6-element Yagi-Uda antenna designed in the Mmana-Gal software is shown in Figure 6 and the antenna diagram is shown in Figure 7.

The Yagi-Uda antennas were made on a wooden ruler with dimensions of 500 mm x 40 mm x 25 mm. The antenna elements consisted of aluminum tubes with a diameter of 6 mm and, these being fixed to the wooden ruler, using screws, washers, and nuts (dimensions 3/32 x 1.1/2 inches), distanced as shown in Figure 7. The final aspect of the assembly is shown in Figure 8.

Figure 6 - Data file, referring to the projected antenna.

```
Yagi-Uda Antenna Project
*
432.6
***Wires***
6
-0.087, 0.0,    0.1715, -0.087, 0.0,    -0.1715,        0.003,  -1
0.0,    0.0,    0.166,  0.0,    0.0,    -0.166, 0.003,  -1
0.037,  0.0,    0.1565, 0.037,  0.0,    -0.1565,        0.003,  -1
0.136,  0.0,    0.1525, 0.136,  0.0,    -0.1525,        0.003,  -1
0.233,  0.0,    0.1525, 0.233,  0.0,    -0.1525,        0.003,  -1
0.378,  0.0,    0.1465, 0.378,  0.0,    -0.1465,        0.003,  -1
***Source***
1,      0
w2c,    0.0,    1.0
***Load***
0,      1
***Segmentation***
800,    80,     2.0,    4
***G/H/M/R/AzEl/X***
0,      20.0,   0,      50.0,   120,    60,     0.0
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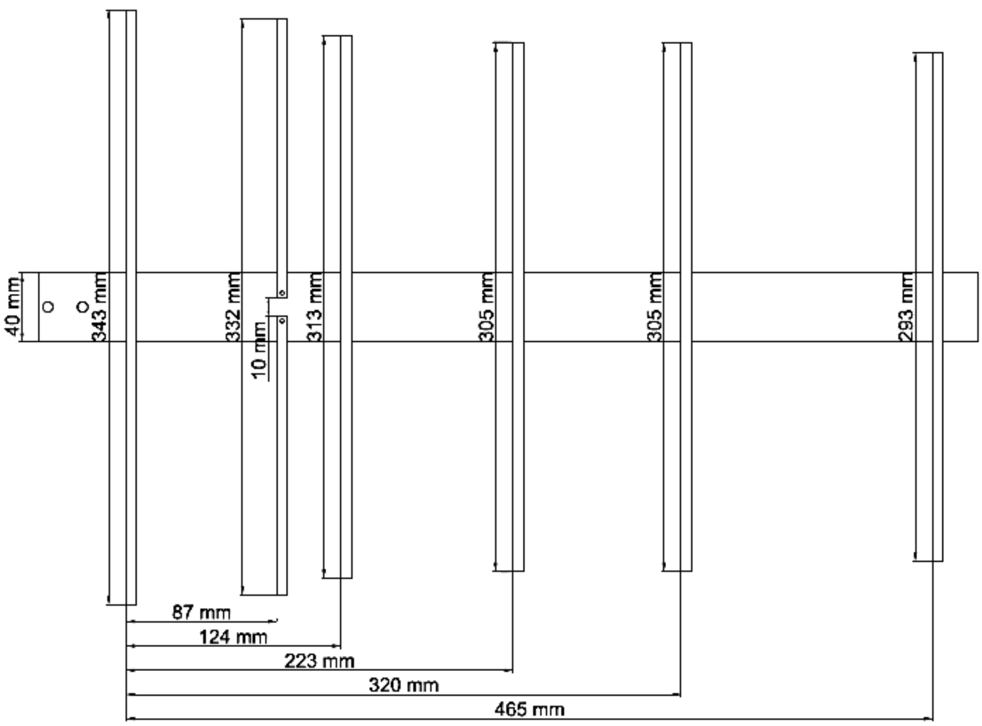
Source: Prepared by the authors (2021).

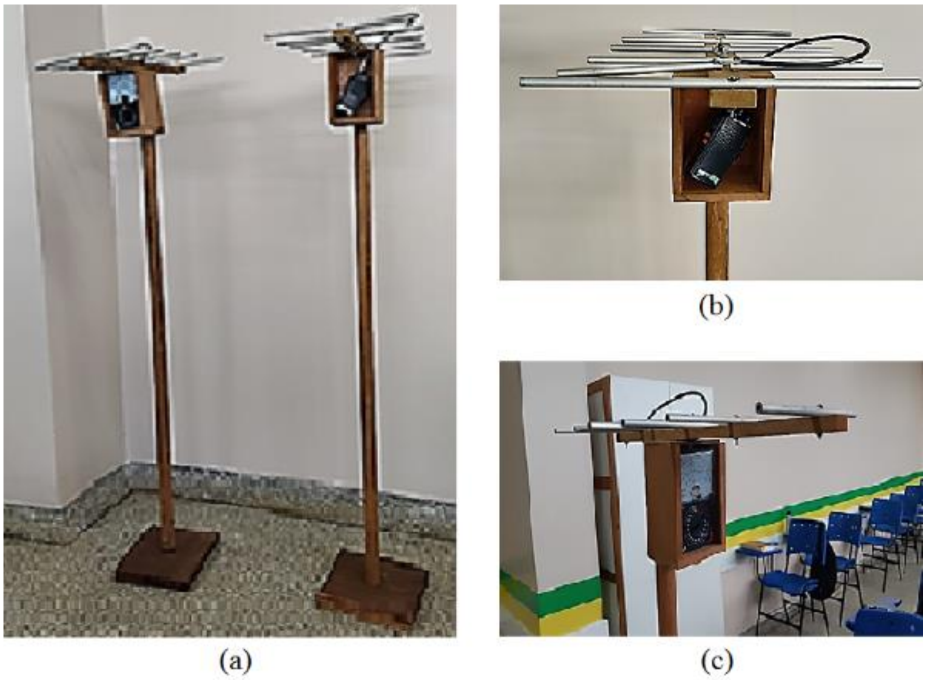
Figure 7 - Yagi-Uda antenna diagram of 6 elements.



Source: Prepared by the authors (2021).

Figure 9 (a) shows the Transmission and Reception System on pedestals; figure 9 (b) shows a detail of the transmitting antenna attached to the transmitting radio and in Figure 9 (c) a detail of the receiving antenna attached to the signal meter is shown; itis also emphasized that it is possible to rotate and position the antennas at any angle so that one can observe the effects related to the polarization of electromagnetic waves. Itis observed that the supports have a base of 0. 27 m x 0.24 m and a total height of 1.47 m, so that they can stay at a height close to the view of the students.

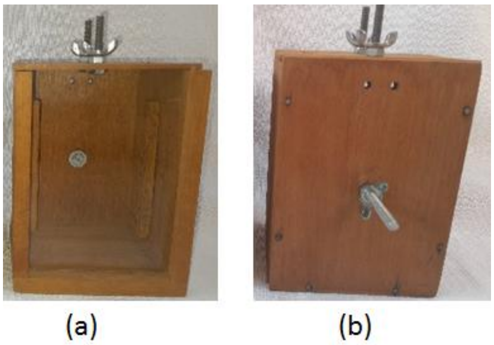
Figure 9 - Transmission and Reception System.



Source: Prepared by the authors (2021).

The wooden boxes intended for fixing the antennas and shelter of the transmitter radio and signal intensity meter have measures of 0.17 m high, 0.10 m wide and 0.11 m long, and at the top of them there are two holes for fixing the antennas, by means of screws and on the back of the box also a hole to fit into the bracket with screws. Figure 10 (a) shows the front and Figure 10 (b) shows the back of constructed boxes, which are identical.

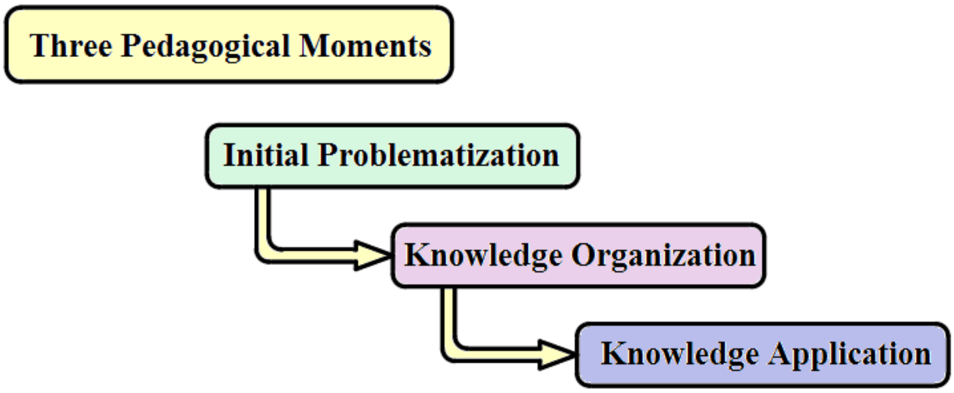
Figure 10 - Detail of the wooden box.



Source: Prepared by the authors (2021).

The activities using the Electromagnetic Wave Transmission and Reception System as a didactic resource were structured in three pedagogical moments, these moments are based on the model proposed by Muenchen and Delizoicov (2014); and being structured as follows: Initial Problematization, Knowledge Organization and Application of Knowledge (Figure 11).

Figure 11 - Three Pedagogical Moments.



Source: Prepared by the authors (2021).

In the first pedagogical moment, real situations are presented, from the day to day of the students, and collected through dialogue about the students' previous knowledge. In this pedagogical stage, students are led and encouraged to observe and describe their conceptions about the subject addressed.

The objective of this phase is to provide students with the possibility of constructing and discussing the interpretations, the proposed situations, besides getting them to seek other knowledge that will help them in the elaboration of an answer.

The Second Pedagogical Moment is the phase that the student organizes his knowledge, through explanations that show that he understood the initial problematization. Thus, in this second moment, a questionnaire was applied based on the topics taught in the first class.

The questionnaire was applied in a class of twenty-four students, with the objective of analyzing what knowledge students have about the subject. The questions asked were of the open type, because they allow a better perception of the knowledge acquired by the students, allowing free thinking and originality and, thus, gather diversified and additional information about the contents studied, as well as to build the profile of the students of the class. Table 1 presents the questionnaire.

Table 1 - Questionnaire.

Question	Question
1	What is the definition of an electromagnetic wave?
2	In what situation of our daily lives are electromagnetic waves applied?
3	How does the interference of an electromagnetic wave happen?
4	How does the refraction of an electromagnetic wave occur?
5	How does an electromagnetic wave reflect?
6	How does a cell phone signal transmission occur?
7	How is the tv image signal transmitted?
8	How is the broadcast signal transmitted from radio stations?
9	How is the signal transmitted and picked up from a satellite?
10	What is the principle of operation of a radar?

The Third Pedagogical Moment is the moment when the student, after organizing his/her knowledge, manages to interfere in the initial problem, and thus employ the knowledge acquired in other contexts related to the contents studied.

This sequence differs from traditional teaching practices, as it does not propose a memorization of a situation or problem or requires mechanical answers to transcribe the contents of the textbook.

Application

The Electromagnetic Wave Transmission and Reception System was used in classes at the Tarcila Prado de Negreiros Mendes Full-Time Educational Center (CETI-TPNM), located in the city of Humaitá, Amazonas State, Brazil. Figure 12 presents the façade of the State School of High School Tarcila Prado de Negreiros Mendes.

Figure 12 – Full-time Educational Center Tarcila Prado de Negreiros Mendes.

Source: CETI-TPNM (2021).

According to the structure of the three pedagogical moments, the didactic sequence of the activities, using this system, were divided into three classes, but due to the pandemic, the classes were working in a hybrid way (face-to-face and online), so the application of this project took place in two classes of the 3rd year, divided into two groups (A and B), classes, in this way were taught twice a week. Therefore, in class only, two applications were needed to cover the students of the class.

Results

The students resumed face-to-face classes in May 2021, and had been without face-to-face classes since May 2020, and it was noticed that students faced many learning difficulties due to the changes caused by the pandemic, and in many situations the lack of preparation of teachers to attend remote classes, as well as in the production and mediation of the teaching and learning process.

Students took classes in the second year of high school, mostly remotely, and half of the third year in the same way. At this time the capital of Amazonas, Manaus, sent the script of classes and the content was studied remotely, and physics classes were taught once every two weeks.

The questionnaire applied in the second pedagogical moment allowed identifying and diagnosing the students' previous knowledge, so, with the answers provided by them, it was possible to perceive that they assimilated the subject, as well as identify their difficulties. Table 2 presents the analysis of the students' answers, as well as the percentage of satisfactory answers from the class of twenty-four students.

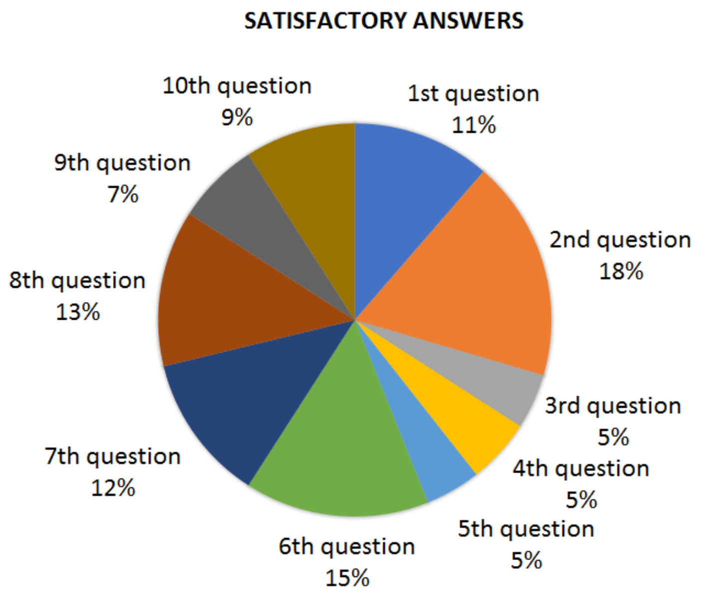
Table 2 - Analysis and percentage of satisfactory answers.

Question	Answers	Satisfactory answers (%)
1	Fifteen (15) students answered this question, they defined the electromagnetic wave as a disturbance, to the transport of energy, to the combination of the electric field with the magnetic and related to speed.	62,5
2	Twenty-four students (24) answered this question, in all answers, the students applied the concept of electromagnetic waves to electrical devices, such as the cell phone.	100,0
3	Six (6) students answered this question about interference, applying the concept to anomalies in the electromagnetic wave, objects that hinder the wave path, superposition of waves in space with explanation for wave interference and related the topic to interference in telephone calls.	25,0
4	Seven (7) students answered this question, applied the subject refraction to the explanation that occurs when a wave changes its means of propagation, was also related to the prism experiment, in the "division of light" (term used by the student), indicating the idea of frequency.	29,2
5	Six (6) students answered this question, in their answers the students explained that this phenomenon occurs when the means of propagation is changed, that the wave spreads again to the middle of origin. One student associated the refraction with the echo example, giving the idea of something that returns to the medium that was focused.	25,0

6	Twenty (20) students answered this question, in their answers the students explained that the operation of the cell phone occurs through a tower, in other answers, satellites and antennas.	83,3
7	Sixteen (16) students answered this question, and they, in most of the answers, explained that their functioning depended on antennas and the capture of electromagnetic waves.	66,7
8	Seventeen (17) students answered this question, in their answers, explained that their transmission is through satellites and propagation of electromagnetic waves.	70,8
9	Nine (9) students answered this question, they performed different discourses in this alternative, in one questionnaire it was mentioned that the satellite signal is captured by a satellite dish, in the other it was mentioned that it is captured by electromagnetic waves and in another it was mentioned that the capture is performed by towers.	37,5
10	Twelve (12) students answered this question, they associated the operation of the radar with electromagnetic waves, satellites, heat by electromagnetic waves.	50,0

Figure 13 presents the percentage of satisfactory answers related to the questionnaire applied, as can be seen in this graph, that in general the students did not have agood previous knowledge, it is emphasized that the 18% referring to the second question, that is, and what situation of our daily lives are applied to electromagnetic waves, was not expressive.

Figure 13 - Percentage of satisfactory answers related to the questionnaire applied.



Source: Prepared by the authors (2021).

In the presence of the application logic, that is, the stage of the application of knowledge, the students actively participated during the assembly and use of the Transmission and Reception System and Electromagnetic Waves; at this time many questions related to electromagnetic waves were induced and answered at the same time as they day to observe in detail the wave phenomena related to electromagnetic waves.

Discussion

Through the application of the Electromagnetic Wave Transmission and Reception System, the students actively participated in the process, because they were able to manipulate the experiment and, thus, provided the students with a better absorption of the content, since they were actively involved in the construction of knowledge, as well as the realization of the experimental activity.

The investigative process is an opportunity for the teacher to adapt the methodology to be developed during the application of the product in agreement with the reality of the students, where he can ask questions that help him in the construction of his knowledge and in understanding the subject. Thus, from the hypotheses raised in the exhibition class, in the resolution of the questionnaire and in the realization of the experimental practice, the students develop their capacity for argumentation, assume a critical and investigative posture from the awakening of their curiosity of the handling of the proposed system.

One of the great difficulties faced by students in physics teaching is to visualize what the teacher is teaching, a practical application, created from a problem situation favors the intellectual autonomy of the student.

Conclusion

Many are the problems and difficulties encountered by the teacher in the classroom, so this work brings the elaboration and application of an experimental didactic proposal that arouses the interest of students, besides a critical training with the ability to widely discuss issues involving the applications of physics in their daily lives. At the beginning of didactic construction, it is necessary that the teacher creates means of allocated knowledge, and that mobilize students to elaborate hypotheses of certain situations.

When the teacher works only situations presented in textbooks, they often end up masking students' difficulties, because the contents and exercises are so simplified that students do not need to perform a more comprehensive interpretation that can achieve their reality and the situations that happen in everyday life. If the teacher works only with textbooks and an exhibition class, he will not give the student the possibility of raising questions about the content taught, only decorating the equations and the main concepts, instead observing a phenomenon, raising a hypothesis, constructing the concept, seeking the solution, and building learning.

The role of the teacher must be actively, in which he helps, coordinates, stimulates the reasoning for students to clarify their doubts, and finally complement the classes with different and significant examples. Thus, the guidelines given to teachers are elaborated thinking about a teaching work that values the students' previous knowledge, that stimulates the elaboration of answers by them, and that the teacher works mainly as coordinator, organizer, advisor, evaluator and very little as an exhibitor of the subject.

It is note point that the active participation of the teacher is fundamental, but this required an intense initial effort, mainly to overcome the inertia of students, accustomed to only exhibition classes. We clarified that the implementation of the project presupposed not only the development of topics closer to the interests of students, but also the development of a methodology appropriate to their more interactive and meaningful participation.

This project led students to understand, even partially, how radio waves propagate, how they can pass through some materials and not through others, how information can be transmitted through radio waves, among many other things. This device raised many questions that, as far as possible, were answered, but also generated a lot of knowledge and learning to the students.

The experimental project allowed the active participation of the students, aroused the interest in the subject, asking them to ask questions related to the content presented and motivated by the exploration of this material that provided these circumstances. Contextualizing and experiencing a practical activity is fundamental for the student to have a good development in school, and the lack of it is also a reason for the lack of interest in the physics discipline. It must be emphasized that experimental practice does not walk alone, it walks along with the theoretical part.

Therefore, it was observed in this practice that the students were able to better visualize the subject, relating scientific knowledge with aspects of their experience, that is, satisfactory results were obtained through experimentation, also causing a greater and better interaction among students, because the doubt generated by one raises a discussion between them capable of helping the understanding of the theme.

In addition to becoming an alternative pedagogical tool for physics classes, the experiment improves the quality of classes by developing and promoting meaningful learning, bringing phenomena to be investigated within the classroom.

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