WIP: Virtual Physics Laboratory Applied to the Study of the Propagation of Electromagnetic Waves

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***Abstract*—This WIP innovative practice paper describes a proposal for a Physics Virtual Laboratory (VL) that aims to democratize opportunities for the use of innovative Physics teaching practices, specifically regarding the propagation of light radiation, available free of charge, with the use of digital technologies, being based on and integrated into an active teaching model, focused on a real-world problem. This proposal is motivated by the fact that Physics is taught, in many cases, as an accumulation of equations and variables that can be difficult to understand and seem disconnected from reality, even though Physics is a Science based on observation and experimentation of natural phenomena, having fundamental importance for Engineering and Computing students. To this end, we presented the development of experimental practice tools that constitute a Virtual Laboratory (VL), such as Remote Experimentation (RE), Virtual Simulation (VS), and Virtual Reality (VR) environment (called Makerverse), of the same physical phenomena, observing the propagation behavior of light radiation as a function of distance variation, with the aim of experimentally discovering the equation that governs such mathematical behavior. At the same time, Project-Based Learning (PBL) was chosen to be integrated into our proposal as a teaching model, due to the promising results obtained by different proponents around the world. Furthermore, the topics studied in our proposal go beyond electromagnetic waves, delving into X-rays, applied to Medical Physics and in-depth in Radiology. Although the proposal was developed for different levels of education, at first it was directed and implemented for two classes of Integrated Technical High School in Electronics in Federal Institute of Amazonas Campus Manaus Distrito Industrial (IFAM-CMDI), with face-to-face and remote meetings. To measure the effectiveness of the proposal and the students' affinity with the process, we used different evaluation tools such as analytical rubric, pre- and post-test statistical study, class observation and satisfaction questionnaire. Preliminary results indicate the proposal is promising in terms of learning effectiveness, as well as student affinity, with emphasis on the use of VR as a tool of great interest to students.**

Keywords— Project Based Learning; Virtual Reality; Physics; Remote Laboratory.

I. INTRODUCTION

Physics teaching plays a fundamental role in the perspectives of Engineering and Computing students, given that the application of its concepts in the real world provides solutions to the most diverse needs of society. However, in Brazil and many other emerging countries, the way this subject is taught, in many cases, is still focused on passive, teacher-centered methodologies, without the use of teaching technologies and being taught as an accumulation of disconnected numbers and equations. with reality [1] [2].

However, as Physics is a science based on the observation and experimentation of phenomena, many researchers recommend carrying out experimental practices in the teaching and learning process [3], allowing the student to visualize, interact and test the theory studied in practice. Among the most common types of these tools are Traditional Laboratories (TL), which are controlled environments prepared for carrying out experiments operated in person [4]. Other formats are Remote Laboratories (RL) or Remote Experiments (RE), which allow experiments to be carried out with geospatial independence [5]. We also have Virtual Simulators (VS), which allow us to carry out approximate demonstrations to reality [6], among which a highlight is Virtual Reality (VR) simulators [7] [8], which can provide immersion and interaction in the experimental simulation process.

Experimental practice has shown positive results in the teaching and learning process regardless of its type [9]. However, in Brazil, due to limited Physics laboratories, equipment, basic structure and teacher training, practical-experimental activities are not widespread in Physics classes [1].

Observing this context, the Project-Based Learning (PBL) teaching model emerges as a promising alternative. However, to be considered a well-founded proposal, it is expected that the creation and application process has intentionality expressed in the conscious integration of the referenced structural aspects [10]. This implies providing the student with protagonism, by presenting a real-world problem, which leads them to carry out an investigation to create an artifact collaboratively, which proposes a viable solution to the initial question [11], and encouraging the use of technology at the same time throughout the entire process [12]. In parallel, with the aim of democratizing the proposal in different contexts, concepts of Blended Learning (BL) [13] were observed, to make the proposal versatile regardless of the form of application, valuing online research and group work, which can be implemented in person, remotely or in a hybrid model.

The chosen Physics topic was the study of electromagnetic waves and their propagation, due to their importance for Engineering and Computing students, in view of their vast field of practical application, such as data transmission, energy transmission, in Medicine, military industry, Radiology, among others. The theoretical framework of this proposal involves the study of electromagnetic waves, their characteristics, different types and applications [14], delimited in X-rays [15] and applied to a real-world Radiology case.

The objective of this work is to evaluate the performance and affinity of students studying Physics for Engineering, submitted to a PBL proposal integrated with different experimental practice tools for the study of the propagation of electromagnetic radiation. To this end, the secondary objectives are to integrate an RE, a VS based on Android devices, a VR simulator (called Makerverse) of the same physical experiment on a website, as well as developing a PBL proposal that can be implemented in face-to-face, remote or hybrid classes. However, initially a preliminary analysis of the proposal is carried out, implementing it in two classes of Integrated Technical High School in Electronics in Federal Institute of Amazonas Campus Manaus Distrito Industrial (IFAM-CMDI), Brazil, observing ethical standards and carrying out quantitative and qualitative evaluations in order to seek evidence of its potential effectiveness, as well as detecting limitations.

II. Methodology

The methodology was carried out on two fronts: the technique, responsible for integrating practice tools on the website, previously developed and validated; and the didactic front, substantiating the main characteristics of the teaching-learning process.

A. Experimental and digital practice tools

In summary, the experimental practice tools are structured by the following steps: choosing the topic; literature review; survey of technologies used; prototyping; tests; evaluation/validation; and availability [16] [17].

The chosen experiment is about the inverse-square law (ISL) [18], which demonstrates the propagation of electromagnetic radiation in the visible light section, in which a light source gradually moves away from a Light Dependent Resistor (LDR), thus expecting an exponential decay of the intensity of the radiation flux perceived by the sensor with increasing distance, with the objective of making students experimentally find the equation that governs this phenomenon. This behavior can be analogous to other waves in the electromagnetic spectrum, such as radio waves, TV, cell phone, Wi-Fi, infrared, ultraviolet, X-ray and gamma.

The literature review looked for works with a mutual relationship or in pairs that use ISL, RE, VS and VR integrated into Physics teaching, which presented a process of development, implementation and evaluation of tools.

The prototyping of practice tools was guided by the lowest cost due to the highest possible quality, with the aim of making the procedures economically viable for replication by researchers and attractive for use by students [16]. As for virtual tools, prototyping was carried out using the steps of technical design of real components, modeling/creation of 3D objects for the experiment, development of interactions, simulation of experimental data and creation of applications [16] [17].

The evaluation and validation process used statistical analysis and the study of error propagation [19] arising from experimentally obtained data treatments, as well as calculations carried out to observe whether the generated data can be used to experimentally deduce the equation of the phenomenon studied.

Finally, a website was developed to integrate and make available all experimental practice tools, as well as the integration of asynchronous and synchronous communication tools between teachers and students, also creating devices for evaluation, feedback and redirection of activities, which facilitate the students' autonomous learning process. Therefore, to advance in the investigation process, the student must find the correct answers at certain points in the proposal or will be directed to support material.

One of the main innovative factors of this work lies in the mutual and complementary association of experimental practice tools based on the station rotation model [13] and integrated into a PBL proposal, in which students are divided into stations called “islands” and work in small groups, carrying out parallel and distinct activities in a defined time interval, which can be carried out in person or remotely.

One of the islands is the VS as shown in Fig. 1B), which allows the offline simulation of the experiment showing how it works, then they move to the RE online station in Fig. 1A), in which students can collect and export the actual data obtained from the experiment. They then pass through the VR offline station as shown in Fig. 1C), which is an immersive and interactive environment that expands reality, enabling the visualization of subatomic particles, internal components of the experiment and complementary videos, among others.

Another two stations are aimed at debating the physical principles studied and processing the data obtained, using the MS-Excel software to perform non-linear regression and achieve at the desired equation. On the other hand, the tools can be used separately depending on the learning context if they do not have access to any of these technologies.

B. PBL didactic proposal

Although there are a variety of interpretations among PBL proponents regarding the precise definition of this teaching model, there is a consensus observed regarding the essential elements that make up a PBL educational proposal. In summary, these characteristics [12] indicate that the student must be a protagonist throughout the entire process, with the

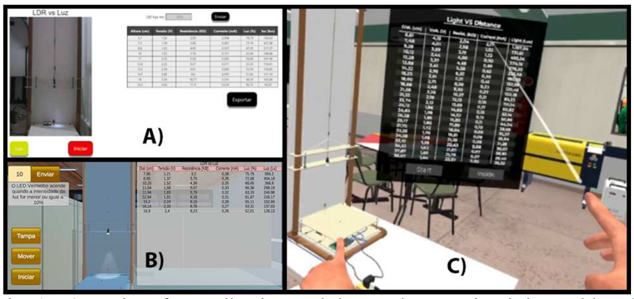


Fig. 1. A) RE interface collecting real data and presenting it in a table. B) Android SV simulator interface C) VR simulator interface. These simulators use real data and apply a statistical error to generate the simulated data.

power of choice and active voice. It must be presented with motivating questions from the real world, which must encourage the narrowing of theory and practice, using different technologies in the process and observing local academic standards integrated with the content available, providing an environment for research and collaborative work to create an artifact, with the purpose of presenting a solution to the initially proposed question.

In this way, the chosen theoretical framework integrates topics from Electromagnetism, Medical Physics and Radiology, meaning that electromagnetic oscillations are studied to understand their characteristics, functioning and uses [20]. Among them, the topic is limited to the use of X-rays, including their discovery, physical principles and applications [21]. Among the applications, use in Radiology was chosen for X-ray examinations [22].

The academic standards used to support this are in accordance with the normative documents of Brazilian Education [23] [24], observing the competencies and skills expected of the students submitted to the proposal. The target audience of the proposal is aimed at undergraduate Engineering students, however, for a prior analysis, the proposal was initially implemented in two classes of the 3rd year (Grade 12) of Integrated Technical High School of the Electronics course in IFAM-CMDI, and in the future may be subsequently applied in Engineering students.

Several distinct forms of assessment were chosen and triangulated to provide more comprehensive results. Initially, an analytical rubric [25] was used based on three pillars: artifact structure; content of the work; and communication of results. Another form of evaluation was the satisfaction questionnaire, with subjective questions, analyzed to measure the frequency of incidence of the most common variables. The statistical hypothesis testing method and the t-Student proof tool for related variables were also used [26].

In parallel, knowing that all research with human beings presents some type of risk, the proposal was presented to the students narrating the entire process to be implemented. Subsequently, a Free and Informed Consent form was given to the students and guardians, detailing all their rights and duties throughout the research, with the researcher being fully responsible for the physical and psychological integrity of the students, as well as the confidentiality and integrity of the data obtained during implementation and possible effects subsequent to its implementation.

Based on the 6 phases of PBL [12], this proposal was structured in 4 stages with 10 synchronous classes as shown in Fig. 2A), in person or remotely, during 50 minutes each. The first of them (two classes) is called “first steps”, responsible for presenting the activity through the video anchor shown in Fig. 2B); division of students into groups; choosing the type of artifact for each team; presentation of assessment parameters and learning objectives integrated into an analytical rubric.

The narrative presented in the anchor of Fig. 2B) introduces the story of a businessman who is building a daycare center on terrain that used to be a parking lot, but recently he discovered that the building next door, which is less than three meters away far from the room that will house his enterprise's nursery, there is an X-ray room. Therefore, the businessman makes a request for consultancy to the students to investigate whether there is any risk for the babies who will

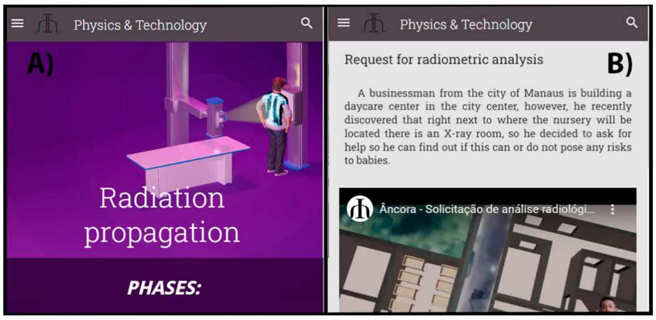


Fig. 2. A) RE interface collecting real data and presenting it in a table. B) VS Android simulator interface.

stay on the premises of this daycare center and asks the students to present viable solutions to avoid having to move.

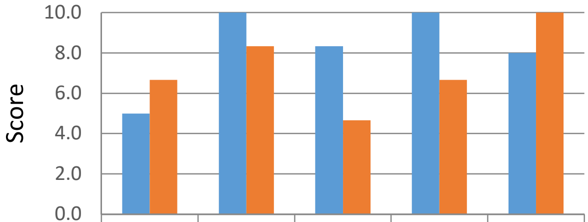
Then, the second stage (three classes) is investigation, in which students carry out research through a Web Quest [27] on the proposal website, with previously selected texts and videos. Subsequently, structured experimental practice activities are carried out using the Station Rotations Model [13]. The third stage (two classes) is called Artifact, in which complementary activities are suggested to fill theoretical gaps or technical research, on the different types of artifacts freely chosen by each group and the final presentation format. The last stage (three classes) consists of evaluation, in which students first carry out self-assessment using the rubric as a parameter, to find errors or gaps, which must be remedied by a complementary visit in the previous stages, to finalize the artifact and its respective presentation. Still at this stage, the groups present their artifacts and are evaluated by the teacher, with or without the possibility of adding evaluation by other colleagues, at the teacher's discretion. Artifacts are posted on the proposal website and students receive their grades based on the rubric.

Throughout the proposal, all activities not carried out synchronously could be done asynchronously at home, as well as during office hours, dedicated between class days to answer any remaining questions.

III. PRELIMINARY RESULTS

The first implementation of this proposal was carried out in two classes of the 3rd year (Grade 12) of Integrated Technical High School in Electronics in IFAM-CMDI, each with 5 teams. We called the first class “A” with 38 students, followed by class “B” with 25 students. The classes had 10 50-minute face-to-face classes and 8 asynchronous remote activities. The results obtained can be divided between: the rubric, responsible for assigning a final grade to students; satisfaction assessment, to observe students' perception of the proposal; and the pre- and post-test, responsible for testing the hypothesis whether or not the proposal can be effective.

The rubric has 3 evaluation criteria, structure of the artifact, the conceptual domain of content and form of presentation. These criteria are ranked at different levels of performance, between 0 and 4 points for assigning a grade, which can be related to the following increasing scale: did not present = 0; insufficient = 2.5; regular = 5.0; satisfactory = 7.5; and excellent = 10.0, in which each level has a series of conditions that must be met to be qualified as such. On the other hand, it is important to point out that all groups made some occasional errors, which suggests their results in the interval between two grades, but as the scale system is discrete, it is up to the evaluator to determine which level of



	Team 1	Team 2	Team 3	Team 4	Team 5
Class A	5.0	10.0	8.3	10.0	8.0
Class B	6.7	8.3	4.7	6.7	10.0

Fig. 3. Final grades of each group for the two classes, coming from the simple average of the three evaluation criteria of the analytical rubric.

performance best fits the work evaluated.

The results of the evaluation of the proposal using the rubric as parameters are presented in Fig. 3. It is important to highlight that although 100% of the groups completed the proposal, there was a discount of 2 points for group 5 of class A and group 3 of class B, due to delays in the delivery of work. The simple arithmetic average for class A was 8.3 and class B was 7.3.

On the other hand, a satisfaction survey, carried out to observe signs of the effectiveness of the proposal in relation to the students' perception, had the following results: when asked about the affinity of the PBL proposal compared to traditional methodologies, 56.3% of class A and 61.9% of class B responded that they prefer methodologies like the one implemented; when asked about their affinity with the experimental practice activities carried out, 96.9% of class A and 100% of class B classified their interactions as positive; Among the practical activities that most caught the students' attention, 40.6% of class A and 71.4% of class B chose VR, compared to the other activities together (RE, SV, data processing activity and construction of artifacts); when asking what was most striking about the proposal, for class A, 28.1% and for class B, 47.6% answered the methodology. For 21.9% of class A and 19% of class B, they chose the content. The other students chose teamwork, practical activities and technologies used or did not respond.

When questioning groups A and B about what could be done to improve the proposal, the results are summarized in Fig. 4, suggesting improvements in website navigation, theoretical classes on the topic, more practical classes, more time, simplifying the proposal and reduce the size of the groups. It is evident that the personal experience of each class was different, which can also be seen in the evaluation results.

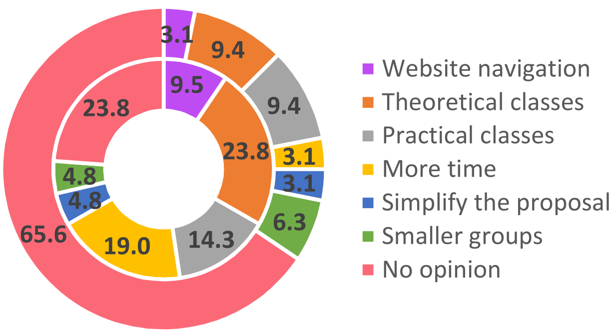


Fig. 4. Graph of variables extracted from students' responses to the question about what they would improve in the didactic proposal. The outer part of the graph represents class A. The inner part with results from class B.

In parallel, the pre-test was also carried out before starting the proposal and the post-test at the end, consisting of nine multiple-choice questions with 4 alternatives. The pre-test average was 3.06 and post-test 6.01 for class A, while for class B it was 3.81 and 5.13, with a positive variation occurring in both cases. To test the hypothesis whether the means improved, the one-tailed p-value was used, being less than the 5% significance level, for class A ($p = 1.16 \times 10^{-7} < 0.05$), and for class B ($p = 2.6 \times 10^{-2} < 0{,}05$). Therefore, in both cases the averages improved due to the application of the proposal.

IV. Conclusions and Impact of the Proposal

The experimental practice tools were integrated and made available on the didactic proposal website as a source of reliable real and simulated data collection, allowing students to have different perspectives on the same physical phenomenon, and can be used in a complementary or substitutive way, depending on the reality of each learning context. They are available free of charge on the proposal website and their results have been published both for RE and VS [17], and for the VR environment (called Makerverse) [18].

The results obtained from the three forms of assessment (analytical rubric; pre- and post-test; and satisfaction questionnaire) converge to confirm the effectiveness of the PBL proposal, indicating improvement in students' mastery of physical concepts, skills and competencies, reflected in the construction of artifacts and carrying out evaluations. The students classified the proposal as stimulating, dynamic, interactive and innovative, with its main highlight being the use of VR, in which the "newness" factor served as a motivator, engaging the class to carry out the activities.

On the other hand, it was possible to detect that class A had a better result than class B. This factor is justified by technical problems experienced mainly with class B. Furthermore, the 4 main factors that hindered better results stand out, and they were used for subsequent adjustments were: a) Methodology - some students reported that out of habit or concern about entrance to University exams, they prefer traditional expository methodologies; b) Access to technologies - was also a complicating factor, in which resources were scarce, relating to devices, Internet and signal quality, making access difficult at the same time; c) Time - in which technical problems limited him in the classroom, resulting in more heterogeneous results; d) Experience – the application of the proposal proved to be inversely proportional to the time required to solve satellite problems in the teacher's daily life.

After some adjustments that were made to try to mitigate the problems detected by the research participants, a Didactic Sequence [28] [29] was created for High School teachers. However, to continue this work, the proposal will be adapted, focused on Higher-level Engineering and Radiology Technician students, observing the limitations detected in the preliminary results, seeking to improve the performance found.

Finally, after observing the positive response from students, the VR environment is being expanded to create a Virtual Maker laboratory, called Makerverse, which will allow immersion in a laboratory that allows not only accessing experiments, but also creating them.

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