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Development of Modeling and Communication Skills through a Project-Based Learning Approach in the Physics Laboratory

Prof. Rodrigo Cutri, Maua Institute of Techonology

Cutri holds a degree in Electrical Engineering from Maua Institute of Technology (2001), MSc (2004) and Ph.D. (2007) in Electrical Engineering - University of SÃo Paulo. He is currently Titular Professor of Maua Institute of Technology,

AIRTON EIRAS

Dr. Octavio Mattasoglio Neto Neto

Undergraduate in Physics (1983), Master in Science (1989) and Phd in Education (1998) all of them from Universidade de São Paulo. Professor of Physics at Mauá Institute of Technology, since 1994 and President of Teacher's Academy at the same Institution.

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This evidence-based practice paper aims to analyze the development of physics modeling competences and soft skills among second-year students in Engineering courses. The main objective is to implement the Project Based Learning (PBL) approach during the Experimental Physics class. The students were divided into teams of four members, and each team was allowed to choose a scientific paper on electricity and magnetism from a Physics journal. These papers were pre-selected by the tutors. The students were required to read and comprehend the proposed physical model and experiment procedure outlined in the original paper. They then had to adapt it to the available equipment in our university laboratory. Once the teams had collected data, they were to analyze and compare it with the physical modeling of the observed phenomenon. Finally, they were to create a self-explanatory video presentation, limited to 10 minutes, where the student teams explained the physical phenomenon, the modeling, the experiment conducted, and the analysis and conclusions drawn. The PBL approach allows students to have a better understanding of important physical theories, including their logical and mathematical structures and experimental support. It also enables them to perform experiments independently and effectively describe, analyze, and critically evaluate experimental data. Additionally, students become familiar with important experimental methodologies and learn how to search and utilize physical and other technical literature as well as relevant sources of information for research and technical project development.

Introduction

The Physics course is offered to second-year students in Engineering courses at the Maua Institute of Technology University Center (Brazil). The course consists of one theory class and one laboratory class per week, each lasting 100 minutes. The main objectives of the Physics course are to promote the following competences in students:

- Develop mathematical models that represent physical phenomena using statistical, computational, and simulation tools, among others.
- Verify and validate models using appropriate techniques.
- Predict the results of systems through models.

Based on previous academic experiences [1-6], as well as the active learning approach [7-12], and assessment methods related to competency-based assessment [13-22], the aim is to develop physics modeling competence and soft skills among second-year students in Engineering courses. We propose that students undertake experimental projects that align with the main course syllabus, specifically focusing on Oscillations, Waves, and Electromagnetism. As a requirement, all projects must include mathematical modeling and analysis of experimental data.

Methodology:

Table 1 [23], [24] presents the evidence that the proposed approach intends to collect in relation to the competences to be developed by the students.

Table 1 – Competences and evidences

Competences	Evidences
Develop knowledge	The students will collaborate with their peers and teachers to conduct a survey and define the theme of their project.

Synthesize knowledge	The project must be written in scientific language.
Communicating knowledge	Additionally, the students are required to create a video presentation that explains the objective of the project, the proposed solution, and an analysis of the results.
Think critically and reflectively	The video should include a comparative and critical analysis of the expected results with the theoretical model and the experimental results obtained.
Demonstrate Engineering skills	Furthermore, the project must be related to the application of physical concepts in engineering problems.

In the laboratory classes, the students were divided into teams of four members. Each team had the opportunity to choose a scientific article on electricity and magnetism from the Brazilian Journal of Physics Education. These articles were previously selected by the team of teachers. The following themes were suggested for the projects:

- The braked rolling of magnets on an inclined plane: an interesting application of the Faraday-Lenz law [25]
- Magnetic drag and Foucault currents: a low cost experiment with video analysis [26]
- Building a DC electric current motor as active learning of the law of Faraday [27]
- The construction of an electromagnetic crane for didactic resources [28]
- Electromagnetic induction – Faraday's Law [29]
- Measuring the mass of a magnet during its downfall [30]
- Magnet movement when sliding on an inclined aluminum plane [31]
- Construction of a pendulum with magnet and coil intended for the education of electromagnetism. [32]

In the laboratory classes, the students were divided into teams of four members. Each team had the task to read and comprehend the physical model and experimental procedure proposed in the chosen paper. They were then required to adapt it to the available equipment in our laboratory. The teams proceeded to collect data, analyze and compare them with the physical modeling of the phenomenon.

A self-explanatory video presentation, up to 10 minutes in length, was prepared by each team to showcase the experiment conducted, data analysis, and the resulting conclusions. The video emphasized the theories and physics concepts used in the project. All activities were conducted outside the classroom, allowing students freedom in choosing their project theme. However, the project had to incorporate data collection and analysis that would enable mathematical modeling, avoiding solely qualitative demonstrations.

The objective of this approach was to develop physics modeling competencies and soft skills, such as teamwork and oral and written communication skills, through a contextualized problem-solving approach. The final presentations, lasting 10 minutes each, were performed before the entire class and evaluated by the teachers. After each presentation, the teachers provided feedback to each team, highlighting the strengths and areas for improvement. A qualitative and quantitative research study was conducted using a Likert-type questionnaire to assess the students' perception. All responses were summarized and analyzed.

The PBL (Project-Based Learning) largely developed by [12] and the PBL that is developed in this paper, that uses scientific journal articles for learning development, although distinct in their approaches, share a central educational philosophy: active and learner-centered learning. [12] emphasis is on solving complex real-world problems, students work in multidisciplinary teams with guidance by an experienced mentor. In our paper, PBL with Scientific Paper, emphasis is on research and critical analysis of scientific information where students develop research and scientific communication skills, deepening in a specific topic of interest to the student, learning through critical reading, scientific writing, and presentation of results. PBL with scientific papers apply principles of WPI's PBL [12], such as team learning and mentoring.

2021 Results

In 2021, a survey was conducted, along with the tabulation of grades and qualitative research with teachers, to assess the students' proficiency in working with the scientific methodology. This involved mathematical modeling and the analysis of experimental data generated from their respective experiments. During the evaluations, teachers not only assigned final grades but also provided feedback to the teams, helping them identify their strengths and areas for improvement.

Out of approximately 150 evaluated works, graded on a scale of 0.0 to 10.0, the results statistics revealed the following distribution [where PG – is project grade] : 34.6% were deemed very satisfactory (PG> 8.0), 59.3% were satisfactory (6.0< PG ≤ 8.0), and 6.1% were considered average (PG≤6.0). The qualitative feedback from faculty members indicated that projects based on scientific articles, where students were expected to develop experiments similar to those described in the articles and achieve similar results, received highly satisfactory evaluations. Moreover, this approach instilled a sense of pride in students, as they felt capable of replicating experiments published in scientific journals.

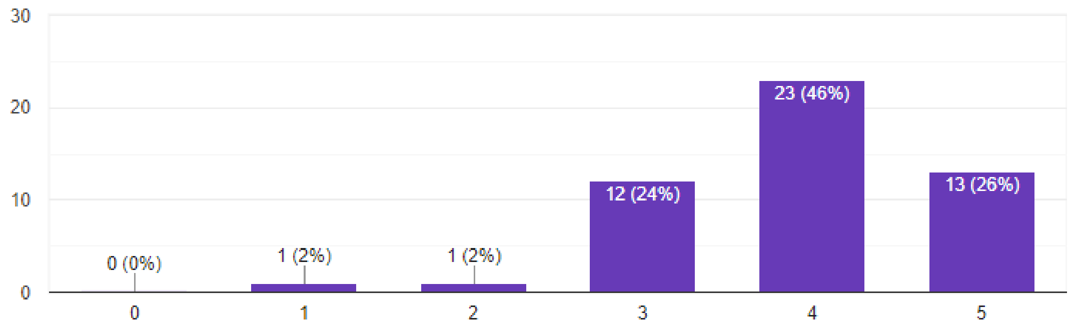
The Project-Based Learning (PBL) approach enables students to better understand critical physical theories, including their logical and mathematical structures, experimental support, and the underlying physical phenomena. It also empowers students to conduct experiments independently, as well as to describe, analyze, and critically evaluate experimental data. Furthermore, it helps students become acquainted with essential experimental methods and equips them with the skills to search for and utilize physical and other technical literature, as well as relevant sources of information for research work and technical project development.

In 2022, a new edition of the project was implemented, involving 326 students. Out of approximately 90 works evaluated on the same scale of 0.0 to 10.0, the results statistics indicated that 93% were classified as very satisfactory (PG> 8.0), while 7% were deemed satisfactory (6.0< PG ≤ 8.0).

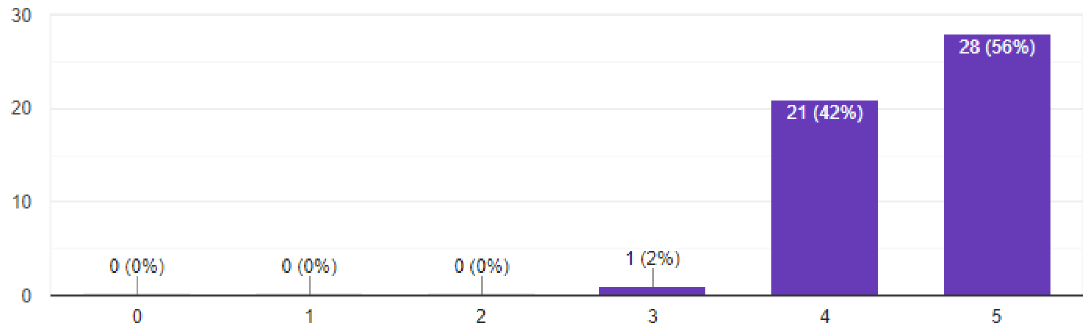
It can be observed that in 2022, students showed significant improvement in the evaluation of their developed projects. This improvement is mainly attributed to the work carried out during the semester of the course, where emphasis was placed on reinforcing the importance of theoretical foundations in each laboratory experiment and on ensuring that the project includes experimental data that verifies the studied theory, specifically in the context of each paper.

To gauge students' perception, a Likert-type questionnaire was administered, utilizing a scale ranging from 0 (none) to 5 (totally). The questionnaire received responses from 50 students, which represents nearly 15% of the total number of students.

Question 1: Prior to undertaking the semester project, how confident were you in your ability to read and comprehend a scientific article?

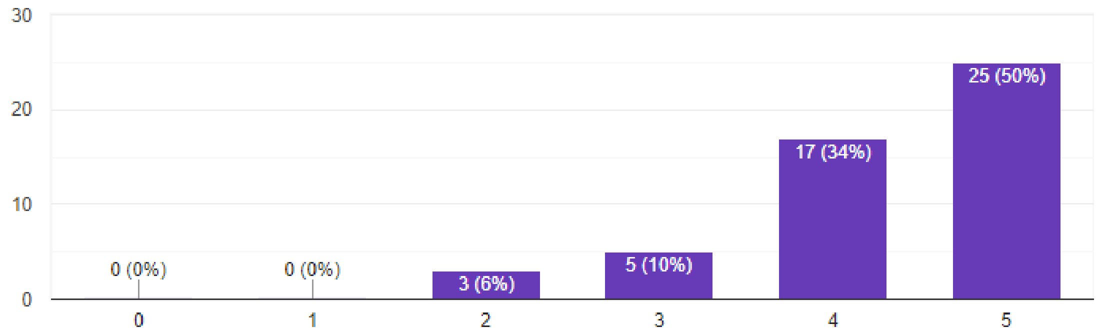


Question 2: In your opinion, after completing the semester project, how confident do you feel in your ability to read and understand a scientific article?

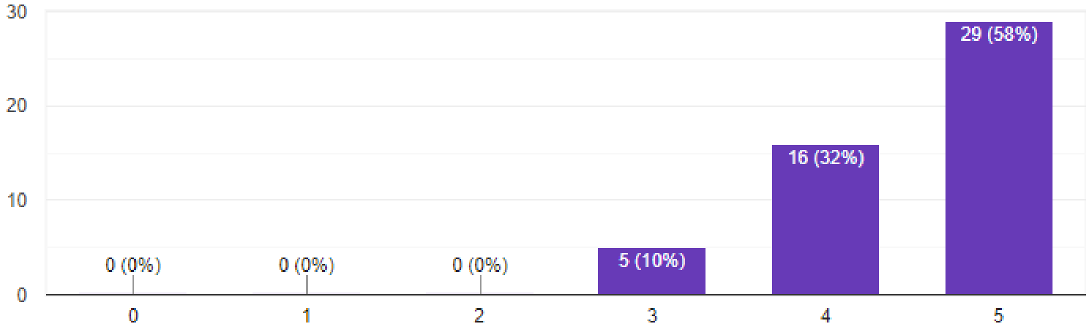


It appears that the perception of students' ability to read and fully understand a scientific article increased significantly from 26% to 56%.

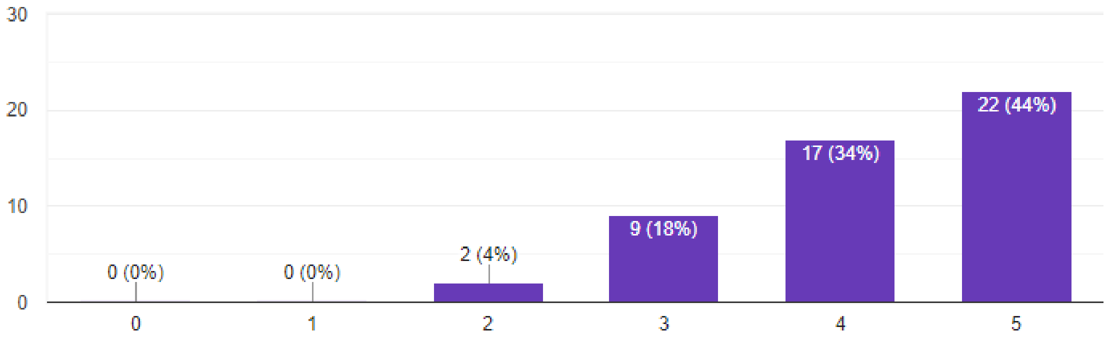
Question 3: In your opinion, did the semester project contribute to a better understanding of important physical theories, including their logical and mathematical structure, experimental support, and described physical phenomena?



Question 4: In your opinion, did the semester project allow you to enhance your ability in conducting experiments independently and critically evaluating experimental data?



Question 5: In your opinion, did the semester project enable you to develop your ability to research and utilize physical and other technical literature, as well as other relevant sources of information, for research work and the development of technical projects?



Based on the information from question 3, it seems that the semester project contributed to a better understanding of important physical theories for 50% of the students overall. Additionally, it helped develop the ability to independently perform experiments and critically evaluate experimental data for 58% of the students (question4), and develop the ability to research and use technical literature for 44% of the students (question 5).

Each paper published in the Brazilian Journal of Physics Education discusses physical theories, including their logical and mathematical structure, experimental support, and described physical phenomena. Therefore, the student's self-recognition that they have understood the theory and mathematical calculations presented in the paper is a significant achievement within their cognitive process. This achievement also strengthens the concepts developed in the theoretical classes of the Physics subject itself.

It can be observed from the presentations made by the students that, in addition to the suggested paper, other literature was researched, especially physics books, to provide a better explanation of the observed phenomenon.

Furthermore, the students reported encountering some difficulties during the project development process, which are summarized in Table 2 below:

Table 2 - Most difficulties encountered during the project development process:

Most difficulties	Amount
Theoretical complexity	5 (10%)
Team's limited time together	4 (8%)
Experimental difficulties	3 (6%)
Theory-practice correlation	2 (4%)
Lack of materials	2 (4%)
Data analysis	1 (2%)
Lab schedule for extra-class use	1 (2%)

It can be observed that the greatest difficulty was in theoretical complexity, but this only accounted for 10% of the respondents. In general, the students expressed the following perceptions:

"The semester project helps me in the practical understanding of physical phenomena."
"Applying the learned concepts was fascinating."
"The project development provided an efficient means to put theory into practice in an autonomous manner."
"Reading papers and using them to define the experiment setup, collect data, and perform accurate analysis was a valuable experience."
"The project proposal presented a new challenge to the group, enhancing our ability to read scientific documents."
"Despite being time-consuming, the project greatly contributed to the learning process."

Also, can be observed that a significant contribution of implementing pedagogical approaches like Project-Based Learning is to foster an emotional connection within the cognitive process. From a psychological standpoint, when students actively engage in their own development, it tends to strengthen their overall cognitive abilities, thereby enhancing their learning and self-growth [33-34].

Some project examples are shared below:

Construction of a pendulum with magnet and coil intended for the education of electromagnetism	https://www.youtube.com/watch?v=KVy2sHBEeV0

Magnet movement when sliding on an inclined aluminum plane -	https://youtu.be/ann7SCBKMKg
Measuring the mass of a magnet during its downfall	https://youtu.be/tn1t3m8mWsU

Final considerations

The project-based learning (PBL) approach allows students to have a better understanding of important physical theories, including their logical and mathematical structure, experimental support, and described physical phenomena. Additionally, PBL enables students to independently perform experiments, describe and analyze experimental data, and critically evaluate their findings. Furthermore, PBL helps students become familiar with essential experimental methods and develop skills in researching and utilizing physical and technical literature, as well as other relevant sources of information for their research work and technical project development.

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