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The use of Engineering laboratories for teaching Physics

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The Use of Engineering Laboratories for Teaching Physics

Abstract: The aim of this work is to present experiences in using Engineering laboratories for teaching Physics. The Physics faculty of Mauá Technology Institute, Brazil, has been striving to align Physics concepts with real-life situations using Engineering laboratories. These laboratories are rich in applied Physics, and these applications can be the key to giving meaning, motivating, and engaging students in Physics course. The institution where this project is being developed has over a hundred laboratories, surpassing the number of traditional classrooms, and also has a research center that provides services to various sectors of society, conducting tests and research in Engineering. The challenge is: how to utilize these Engineering laboratories in the teaching of Physics? When students enter an Engineering course, they are eager to practice Engineering from the start, and often feel unmotivated when faced with Physics that is not well contextualized within the course. With this need for contextualization in mind, coupled with teachers' awareness, the aim was to find a set of experiences that would put students in contact with the Physics found in Engineering. To develop this proposal, the faculty began prospecting in the institution's laboratories, aiming to identify processes and phenomena that could be studied from the perspective of Physics concepts and laws. Four laboratories were selected to start the project: Advanced Manufacturing, Automotive, Machining and Materials laboratories. As approximately 300 students enroll each year, the proposal is for student teams to work in one of the school's laboratories. Each team should collect data in the host laboratory, describe the process, identify the Physics concepts involved in modeling the phenomenon, present collected data and achieved results, highlighting potential Engineering applications. Furthermore, each team should prepare a presentation, showing the phenomenon in the host laboratory and reporting on the work done. The presentation, given at the end of the semester to the entire class, will ensure the sharing of experiences with other students. To assess learning in this project, students will take a pre-test and a post-test on the concepts and physical modeling related to the phenomenon studied in the host laboratory. Additionally, a questionnaire will be administered to gauge students' and teachers' perceptions of the work proposal. The purpose of presenting this work at the conference is to share the structure of this project and the initial results achieved.

Introduction

At the private, non-profit educational institution Mauá Technology Institute (Brazil), students in the second academic year of Engineering programs are required to take the Physics II unit. This unit syllabus covers topics such as simple harmonic motion, electric fields, magnetic fields, Maxwell's equations, and electromagnetism. The primary teaching objective of Physics II is to develop student's skills in creating, validating and applying models that describe physical phenomena.

In the final quarter of the unit, students work in groups to complete a final project that involves conducting an experiment in the Physics laboratories. Each group selects one experiment from a set of five options, all of which are based on concepts covered in the theoretical classes. Guided by a script, students see in practice what they studied in the traditional classroom. The script also includes a scientific article as supporting text. The combination of hands-on practice and subsequent research equips students with enough information to discuss the phenomenon.

Learning outcomes are assessed through a group presentation about the phenomenon to classmates and instructors. This project-based learning (PBL) methodology was previously discussed by Cutri, Eiras and Mattasoglio Neto [1]. In summary, the authors reported that the laboratory practices enhance student's understanding of theory in addition to reading and interpreting a scientific article and reproducing an experiment reported in that scientific article. During projects, students act more independently and develop skills to experiment and research, to collect, interpret and use data, and, consequently, to describe physical phenomena.

The Physics II practices aim to leverage the benefits of PBL, which include promoting active learning, and providing opportunities for teamwork, investigation, problem-solving, communication, and data management [2]. However, it is questioned whether the PBL methodology could be more efficient in the teaching-learning process in the context of the educational institution in question. A key aspect of PBL is realism or contextualization. To better fit into PBL, the projects must involve authentic problems that are observed in practice. Do the proposed challenges involve concepts that students can relate to real-world Engineering? Integrating these projects into the context of the specific areas of Engineering that interest students may serve to further enhance motivation and engagement. In this scenario, it is anticipated that students will demonstrate better skills and deeper knowledge during assessments.

Thus, in this investigation, we analyze the current Physics II projects currently offered at Mauá Technology Institute. Evidence was obtained from students' perceptions, gathered via survey responses. Based on these findings, we proposed a refined PBL approach that can be applied in Physics units aimed at Engineering students. The new proposed projects explore Engineering laboratories, so that practical classes are conducted in the context of the students' areas of interest.

Methodology

In 2024, following all presentations, students were invited to anonymously participate in a survey about their final projects, administered via Google Forms. Questions were asked regarding the students' opinions on their capabilities and the contributions of the project to their development. Additional questions encouraged self-assessment. Responses were collected using a discrete scale ranging from 0 to 5. Furthermore, a Likert scale was employed to specifically assess whether the project fostered engagement and contextualized the content within the Engineering field. Students were also given the option to provide open-ended responses if they felt that the predefined scales were insufficient to fully capture their views. For report purposes, questions and responses were translated from Portuguese.

Results and discussions

Survey on current projects

Of the 174 active students at the end of the unit, 102 (59%) responded to the survey. Figure 1 shows the distribution of the respondents across Engineering programs. Most students enrolled in Physics II were from Industrial, Computing, Mechanical, and Chemistry Engineering programs. At Mauá Technology Institute, students select their Engineering specialization early in their second academic year.

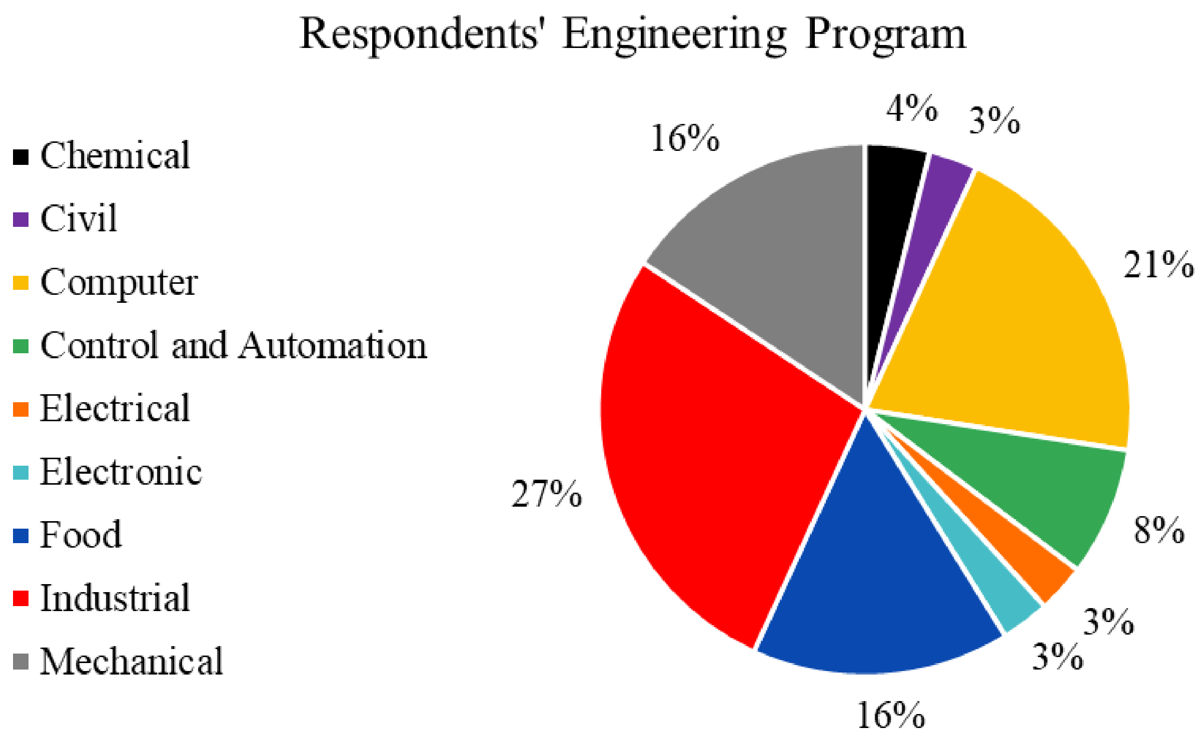

Figure 1. Respondents' Engineering programs.

The first questions regarding the project were: “In your opinion, before/after completing the semester project, how capable did you feel of reading and understanding a scientific article?” Responses were recorded on a discrete scale from 0 (“I felt I was not capable”) to 5 (“I felt completely capable”). Figure 2 shows the responses to these questions.

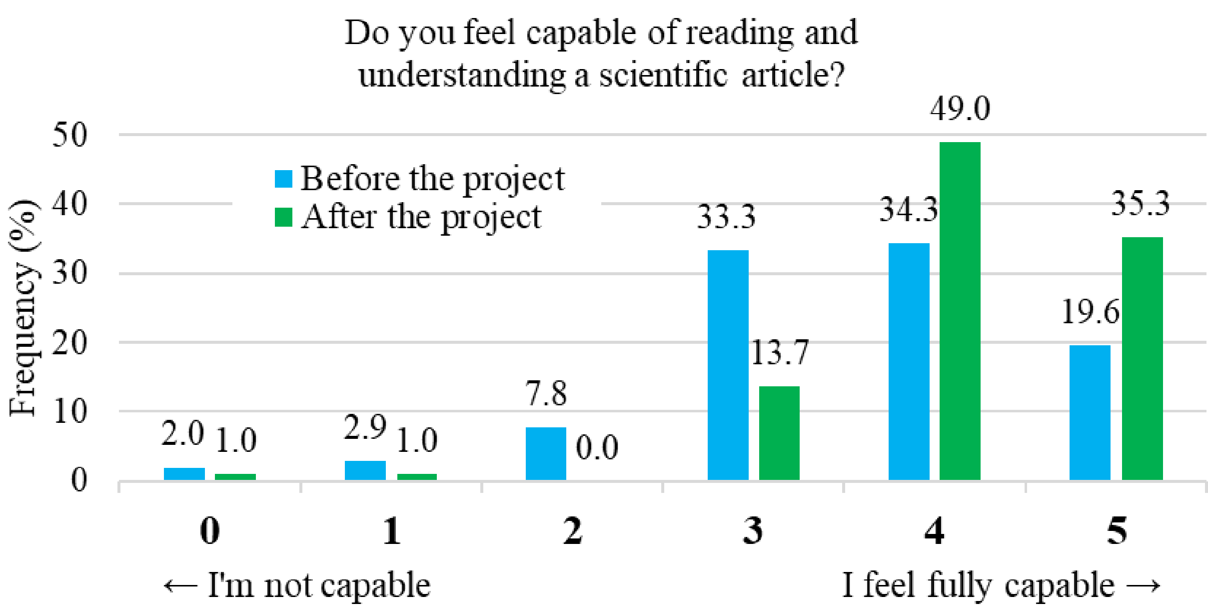

Figure 2. Students' perceptions regarding their ability to read and understand a scientific article.

Most students indicated that they felt capable of reading and understanding scientific articles. Before the project, 87.3% of students selected a score between 3 and 5. After completing the project, this percentage increased to 98.0%. The average score improved from 3.5 to 4.1, suggesting that the project enhanced students' familiarity with scientific articles. One student remarked that the project encouraged “the development of reading scientific articles. Very important for the career”. However, two students from the Industrial Engineering program stated that they still felt unable to utilize such sources of information, contrasting with the other 26 respondents from the same program who did not report similar difficulties.

One of the reasons why the Physics II faculty requested that a scientific article be read to complement the discussion on the project is to foster the development of information literacy and scientific communication skills early in the Engineering curriculum. Students who have opportunities to work with this type of literature are more confident when producing scientific writing and demonstrate enhanced analytical and research skills [3]. The opportunity offered by this project is not unique: at Mauá Technology Institute, students encounter scientific literature throughout the entire Engineering program. The gradual exposure to scientific literature contributes to the development of critical skills necessary for analyzing, evaluating, and applying information [4,5].

The survey then asked students to evaluate how the project contributed to their learning and development. The questions were:

- Contribution A: “In your opinion, did the semester project contribute to a better understanding of important physical theories (logical and mathematical structure, experimental support, physical phenomena described)?”;
- Contribution B: “In your opinion, did the semester project allow you to develop your ability to independently perform experiments, and critically evaluate experimental data?”;
- Contribution C: “In your opinion, did the semester project allow you to develop your ability to search and use physical and other technical literature, as well as any other sources of information relevant to the research work and development of technical projects?”.

Figure 3 summarizes the students' responses, given on a discrete scale from 0 (“did not contribute”) to 5 (“contributed strongly”). In all cases, over 86% of respondents selected scores equal or greater than three, indicating that the project was perceived as beneficial to their understanding of the theory or to the development of skills.

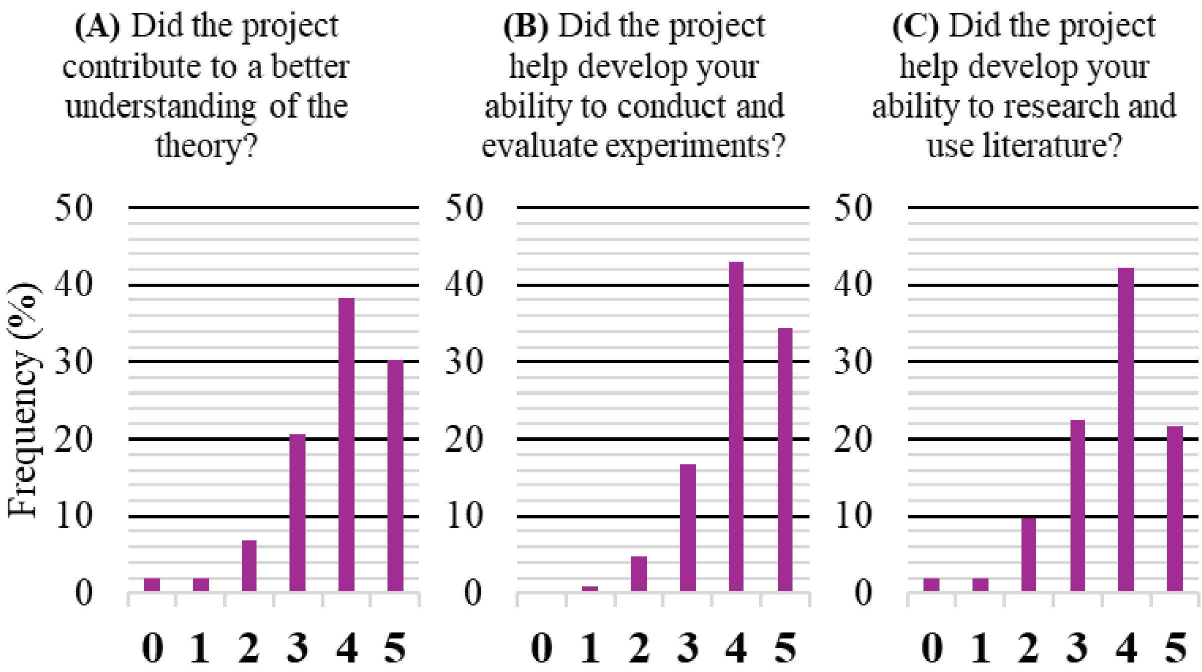

Figure 3. Students' perceptions of the project's contribution to learning and development. Discrete scale from 0 (“did not contribute”) to 5 (“contributed strongly”).

On average, students indicated a score of 3.8 in relation to contribution A regarding the understanding of theory (Figure 3a). The predominant positive perception (89.2% selected a score equal or greater than three) was expected, since enabling a deeper understanding of theory is a common objective of classes in educational laboratories [6]. As suggested by the research of Edward N. S. [7], in Engineering education, both educators and students agree that laboratory activities are valuable for integrating theory and practice.

Students described the project as “very useful for understanding the content in a practical way”, “important for a better understanding of the phenomena”, “an excellent way to combine practice and theory”, and “very good for delving deeper into the content”. Two students said about the development of the project: “it was good because I was able to understand the theory better” and “it contributed a lot to learning and understanding the subject”. Another student stated that the project “was done in a way that valued the understanding, in practice, of previously abstract concepts”.

The average score for contribution B, associated with developing the ability to perform experiments and evaluate experimental data, was 4.0 (Figure 3b), with only 5.9% of students assigning scores below three. In a colloquium proposed by ABET, an organization that accredits educational programs, experimentation and data analysis were considered fundamental objectives of educational laboratories, which include the ability to adopt and implement a procedure, as well as collect and interpret results and form conclusions [8]. According to Smith et al. [9], visits to laboratories with the aim of developing experimentation skills can be advantageous compared to visits with the aim of reinforcing the content covered in the classroom. Practice focused on experimentation can bring engagement and the ability to develop procedures and relate data and models. In the survey, one student stated that the projects were “quite interesting for our development, since we need to understand and perform the experiment by ourselves”.

Contribution C, which refers to the development of the ability to research and use relevant information sources for technical or research work, had an average score of 3.7 (Figure 3c). The contribution was judged to be equal or greater than three for 86.3% of the students. The positive perception is in line with the results of Figure 2, which suggests that the project is useful for the development of information literacy.

Overall, up to three students expressed a score lower than three for each of the five projects, but, as an exception, five students indicated that the project related to Faraday and Lenz's laws made limited contributions to their understanding of theory and to their ability to search for and use information (contributions A and C). The result may highlight the need for refinement in this specific project to better bridge the gap between what is observed in the laboratory and the theory seen in the classroom. Interventions by instructors may also be necessary to promote students' research skills.

The survey enables understanding how students from different Engineering programs perceive the contribution of the project offered. Scores lower than three for contributions A and C were expressed by up to three students from each program, except for the Industrial Engineering program. For this program, scores lower than three for contributions A and C were expressed by four and six students, respectively. The results suggest the need for improvements in theoretical and/or laboratory classes, adapting them to this specific profile of Engineering students. An authentic assessment, which allows students to confront existing challenges in the chosen professional area, may be more effective in achieving teaching objectives [10]

Part of the survey consisted of students self-assessing their modeling skills. Responses consisted of discrete scores from 0 (“I do not feel capable”) to 5 (“I feel fully capable”). Self-assessment was based on three criteria:

- Criterion A: “Do you consider yourself capable of modeling phenomena and physical systems using mathematical, statistical, computational and simulation tools, among others?”;
- Criterion B: “Do you consider yourself capable of verifying and validating models using appropriate techniques?”;
- Criterion C: “Do you consider yourself capable of predicting the results of systems using models?”.

Figure 4 shows that 98.0% of students scored themselves at three or higher across all criteria, with an average score of 4.0. Cascarosa et al. [11] observed that model-based teaching facilitates learning and results in students being able to build robust models and have a deeper understanding of the topic. When presenting the models they created to their classmates, students need to defend and criticize their own work, a task that promotes scientific communication and critical thinking. Models can be considered teaching tools that connect theory and practice. Future projects could explore the application of models in simulations, which tend to reinforce learning by allowing students to check their conceptions.

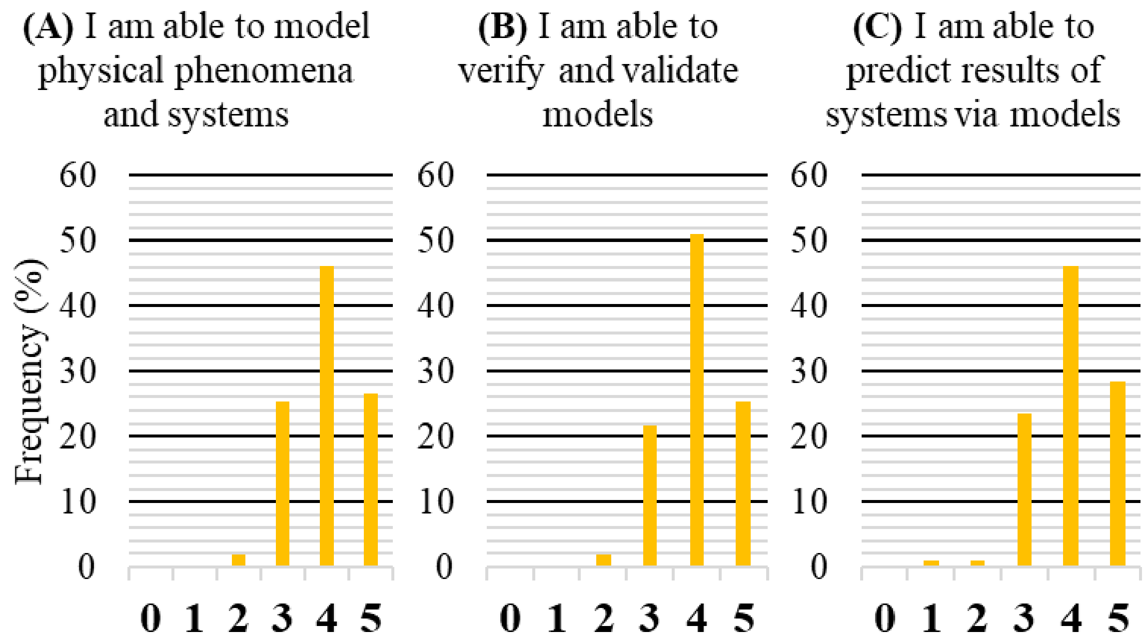

Figure 4. Students' self-assessment of modeling skills. Discrete scale from 0 (“I do not feel capable”) to 5 (“I feel fully capable”).

Finally, the survey asked whether the project contributed to engagement in the Physics II unit and in the Engineering program in general, and whether it helped to contextualize the content within Engineering in general and within the chosen area of Engineering. The responses, shown in Figure 5, were structured using the Likert scale. Most respondents (77.5%) agreed or strongly agreed that the project contributed to engagement in the unit (Figure 5a). This is one of the objectives of including the project as an active methodology in the teaching plan: students are expected to assume a dynamic position in the learning process [12]. Regarding engagement in the Engineering program, 64.7% of students responded positively. To reinforce the engagement of Engineering students, Fajardo and Rajabikhorasani [13] suggest improvements in practical activities in laboratories. A questionnaire about the content, as preparation before going to the laboratory, and a meeting with the instructor, as preparation for the final presentation, can reduce the gap between the results demonstrated by students and the teaching objectives.

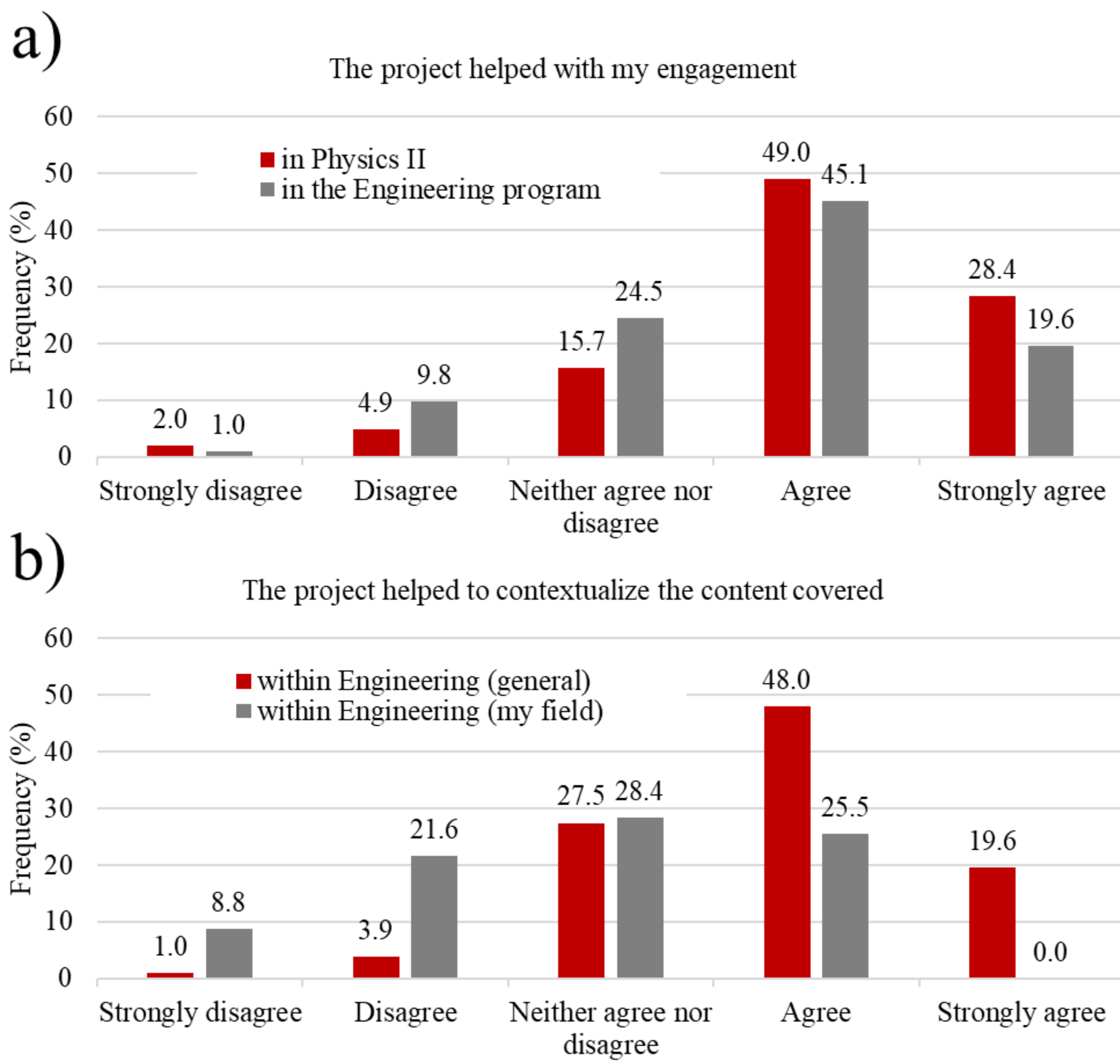

Figure 5. Students' perceptions regarding the project's contribution to engagement (a) and contextualization within Engineering (b).

Among the students questioned about the project's contribution to contextualizing the content within Engineering in general, 67.6% responded positively (Figure 5b). One student stated that the project is “important for applying the principle in everyday life.” However, only 41.2% agreed that the project is in the context of the specific area of Engineering chosen. For example, 23.8% of Computer Engineering students disagree with this contextualization. One of them indicated that one of the difficulties during the project was “finding how to use the experiment in Engineering practice.” An Industrial Engineering student suggested, for future projects, the “analysis of applications practiced in the real world, moving away a little from the applications created in the laboratory.” A Food Engineering student expressed that he/she would like to see a laboratory activity related to his/her area. Adapting these laboratory practices so that students can investigate challenges in their professional area of interest can be advantageous for the teaching-learning process. Contextualization can bring motivation, facilitate the connection between theory and the real world, emphasize the importance of what is being taught, and promote a deeper understanding of the topic addressed [14].

In summary, the survey results indicate that the project effectively contributes to student engagement, deeper understanding of concepts, and development of critical skills in scientific inquiry, experimentation, and modeling. More evidence could be collected to confirm the results of this survey. For example, a diagnostic assessment could be conducted before the project, so that after the project there is enough information to verify the progress, or lack thereof, of students' skills and understanding.

Proposal: teaching Physics in Engineering laboratories

In the survey, the highest rate of disagreement occurred on the issue of contextualizing the project within the realm of Engineering. Physics is undeniably important as discipline, regardless of whether students see its connection with Engineering or not. This academic area can be a valuable entry point to Science, fostering initiative, creativity, and the development of skills associated with logical thinking, abstraction, observation, experimentation, and problem-solving [15]. Nevertheless, its benefits at the educational institution in question could be significantly enhanced if Engineering students were able to grasp how Physics is present in real-world applications.

Thus, here the authors propose utilizing Engineering laboratories as platforms for Physics practices. The Physics faculty plans to devise a “menu” of practical activities, each linked to themes commonly encountered in Engineering. Each group will be able to select a project that aligns with their interests. For the pilot phase, four practices have been designed for Physics I, unit that addresses topics such as kinematics, Newton's second law, center of mass, linear momentum and energy. These projects will be introduced in the first semester of 2025 in the Physics I unit instead of Physics II, due to the ease of implementation.

Figure 6 highlights the focus of these four practices. Students will visit Engineering laboratories to explore real-world applications of Physics concepts. Each project is designed to make students perform observations and record data, culminating in a presentation to classmates and teachers in which questions should be answered. The script includes theoretical foundations on the topic, and questions that encourage students to consult scientific articles to support their discussions.

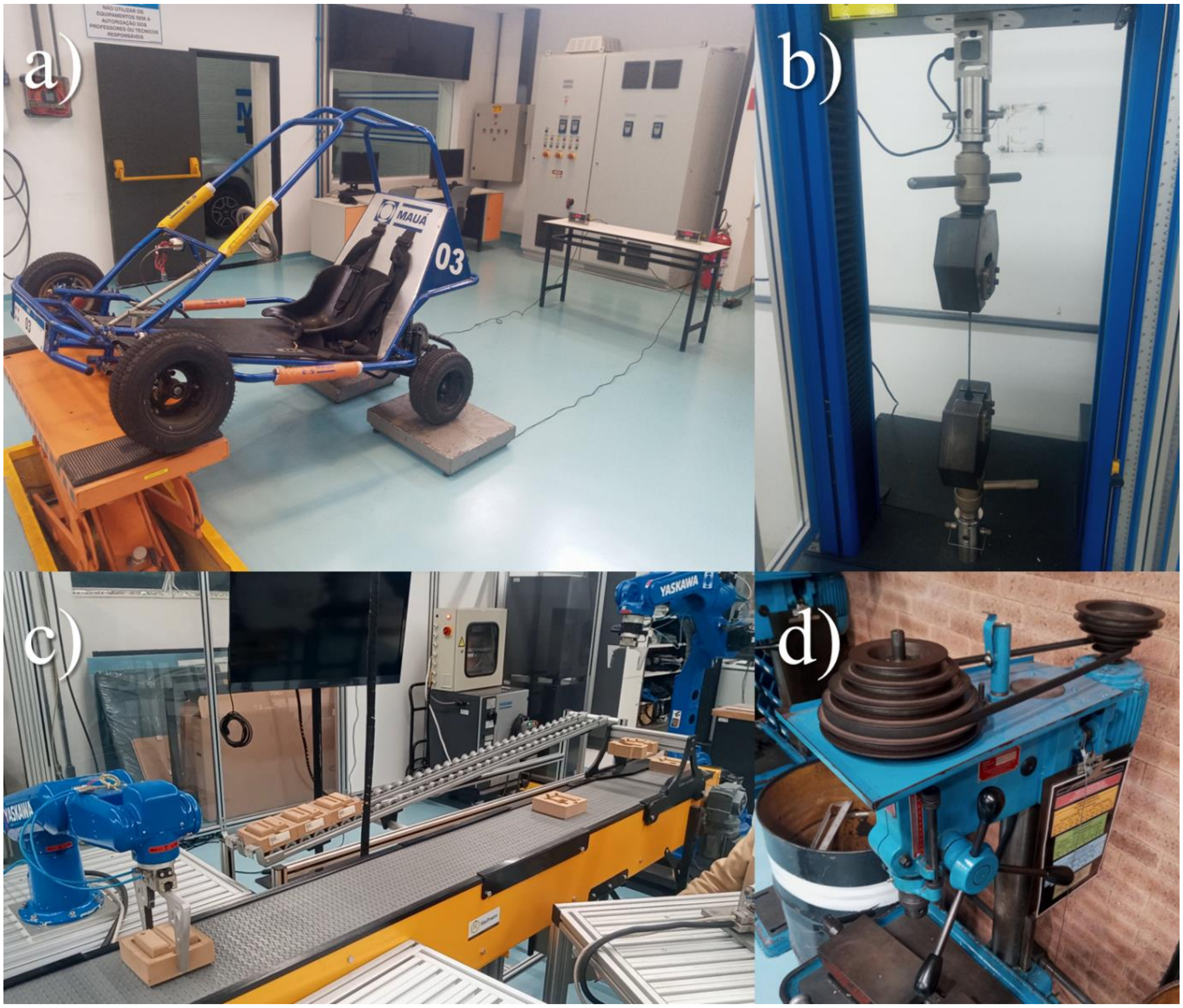

Figure 6. Physics projects designed for Engineering laboratories, specifically automotive (a), materials (b), advanced manufacturing (c) and machining (d) laboratories.

The four projects are briefly described below. In the future, it is in the institution's interest to offer more projects to bring more activities to the Engineering laboratories. These activities aim to not only serve as an effective teaching strategy but also to help reduce dropout rates. Future projects could take place in other laboratories, such as those used by Chemical or Food Engineering programs, so that a greater variety of student profiles may be interested in Physics education, and thus value it and make better use of it.

Project 1 – Minicar at the Automotive Laboratory (Figure 6a): Students will use scales and an automotive lift to measure the longitudinal, transversal, and altitudinal positions of a minicar's center of gravity (CG) based on the analysis of the vehicle's static equilibrium. Students will observe the impact of tire pressure and damping settings on these positions. The script encourages reflection on practical implications such as the influence of the CG position on the car's operation (maximum acceleration without wheelie, maximum slope the vehicle can navigate, etc.). Students must also determine how the presence of a driver alters the system's CG position.

Project 2 – Tensile machine at the Materials Laboratory (Figure 6b): Physics I students are usually introduced to Hooke's law during the study of elastic force, but they do not have the opportunity to appreciate the importance of this law in Materials Science and Engineering. This project introduces students to a tensile machine, used to test different gymnastic elastic bands. A force versus displacement graph will be generated, and from this result the group must determine the elastic constant. A stress versus deformation graph will also be obtained, so that the elastic constant can be related to the modulus of elasticity, both properties associated with the stiffness of the material. As comparison, the elastic constant will be determined using weights, as is usually done in Physics laboratories. The script asks the group to reflect on the elastic constant of different everyday objects and encourages exploration of introductory concepts of Materials Science and Engineering.

Project 3 – Conveyor belts and robotic arms at the Advanced Manufacturing Laboratory (Figure 6c): a simulated assembly line represents an opportunity to study kinematics and static equilibrium. Treating the roller conveyor belt as a frictionless inclined plane for modeling purposes, the group must determine the maximum slope so that the part does not accelerate uncontrollably. The motorized conveyor belt will be programmed to have intermittent movement. The acceleration of this conveyor belt must be evaluated so that the object being transported does not slip or tip over. Robotic arms performing circular and repetitive movements provide opportunities to study circular motion, centripetal force, and frequency. Additionally, students will learn about gears by studying the perpendicular connection between the electric motor and the axis of the motorized conveyor belt.

Project 4 – Benchtop drill press at the Machining Laboratory (Figure 6d): simple equipment where circular motion and torque transmission are seen in practice. Students will see how the rotation of the electric motor can be increased or reduced using mechanical mechanisms (belt position on any of the five pairs of pulleys). The script asks the group to determine the rotation of the drill bit based on the motor rotation and pulley diameters. Students will also explore the relationship between frequency, angular velocity, and tangential velocity, as well as the relationship between power, torque, and speed. In this project, students will explore the influence of the rotation speed of the drill bit on the machining process, and the influence of the lever arm on the torque that the operator must apply to advance the drill bit.

Conclusions

The PBL approach is integrated into the Physics II curriculum for Engineering programs at Mauá Technology Institute. A recent survey revealed that most students hold a positive view of these projects, recognizing their contribution to a deeper understanding of concepts and to the development of experimentation and research skills. Additionally, the teaching methodology also allows students to practice the creation and application of models. Despite this, opportunities for improvement were identified, particularly in fostering student engagement. To address this, the Physics faculty of the institution aims to design projects closely aligned with specific areas of Engineering, enabling students to see the direct relevance of Physics in real-world applications. Thus, it is expected that better learning outcomes will be achieved. As of now, four Physics I projects have been designed, and should be conducted in the institution's Engineering laboratories. Later, the projects will also include Physics II concepts. Subsequent reports on this initiative will detail the challenges of implementing such projects and evaluate the extent to which they achieve the expected educational objectives.

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