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Study of Speeds of Collision in Traffic Accidents: Physics Modeling Competences and Soft-Skills Development

Dr. Rodrigo Cutri, Mauá Institute of Technology, Brazil

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

Dr. Nair Stem, Mauá Institute of Technology, Brazil

- Associate Professor at Instituto Maua de Tecnologia - CEUN-IMT - Graduated at Physics (Bachelor) at IFUSP, Master at Electrical Engineering and Doctor at Electrical Engineering at EPUSP.

Dr. Octavio Mattasoglio Neto Neto, Mauá Institute of Technology, Brazil

Undergraduate in Physics (1983), master in Science (1989) and phd at 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 of the same Institute,

Study of speeds of collision in traffic accidents – physics modeling competences and soft-skills development.

This complete evidence-based practice paper analyzes the development of Physics modeling competencies and soft-skills of First Year Students in Engineering courses. In the Physics laboratory, there are three types of activities: a) Weekly laboratory experiments, b) Applied Physics Seminars and c) Problem learning projects. This work is focused on Applied Physics Seminars where students by using a simulator software "Speed Calculations for Traffic Accidents" – SCTA study the process of collision in a real situation, developing a role similar to the one performed by a forensic investigator where by means of the skid mark and type of pavement he can estimate the initial vehicle speed. In the Physics laboratory, teams of students must: 0) Read the original paper about "Speed Calculations for Traffic Accidents" and pay attention for general teacher's explanation during class laboratory, 1) Use Design Thinking methodology for project planner, 2) Do Physical modeling of the phenomenon trying to extend the model that was presented in the original paper, 3) Do simulations and check model's validity (by means of graphic analysis and comparing the fitted curves to the model predictions), and 4) Prepare a presentation about the selected traffic accident scene, explaining the model of the original paper, and presenting their graphic analysis, as well. In this way, through a contextualized problem, we intend to develop physics modeling competencies and soft-skills like teamwork, oral and written communication skills. Their final presentations were performed to the whole class and they were evaluated by rubrics. At the end of each final presentation teachers showed both the good points and the points that had to be improved to the teams. In order to verify the students' perception regarding the development of the project, a Likert-style questionnaire was applied. In 2020, 70 responses were received from a universe of 600 students (approximately 12%). More than 66% of the students found the theme of the project interesting or super interesting, and for more than 88% felt the time was adequate to carry it out, 93% of the students found the guidelines for the project adequate, and for 96% the previous presentation of the rubrics helped them to better prepare the work. For 82% of the students, the project improved the understanding of the theory and for 82% it presented applications involving physics applied to engineering. In 2021, during pandemic, the project was not evaluated. In 2022, the "evaluation laboratory" tool of Open LMS was added to the project in design thinking methodology. Using this tool, students can submit the initial seminar planning to be evaluated by teachers and at the same time do peer review of other groups activities. They can ask questions and make reflections about other groups activities so developing critical thinking during this process before submitting the final seminar presentation. The project has attended expectations, resulting in better academic performance, as well as contributing to the development of the competencies and skills that were aimed to be developed.

Introduction

The Physics subject is applied to the First-Year students of the Engineering courses at the Maua Institute of Technology - University Center and has one theory class and one laboratory class per week, each with 100 minutes, observing the following syllabus:

Theory: physical quantities and their measures. Motion in two or three dimensions. Applied forces. Newton's laws. Equilibrium of particle. Dynamics of particle. Work and kinetic energy. Potential energy and energy conservation. Power. Momentum, impulse and collisions. Center of mass. Equilibrium of rigid bodies. Laboratory: Physical quantities and their Measures.

Measuring instruments. Experiments involving the topics of the subject matter and Physical modeling.

The Physics subject aims to develop the following Physics modeling competencies and soft-skills of First Year Students in Engineering courses:

• Being able to model phenomena, physical and chemical systems, using mathematical, statistical, computational and simulation tools, among others.
• Predicting system results through models
• Checking and validating the models using appropriate techniques;

Thus, based on previous academic experiences [1], [2], [3] and [4] and an active learning approach [5], [6] and [7], in the Physics laboratory, there are three types of activities: a) Weekly laboratory experiments, b) Applied Physics Seminars and c) Problem learning projects. This work is focused on Applied Physics Seminars where students by using a simulator software "Speed Calculations for Traffic Accidents" – SCTA study the process of collision in a real situation, developing a role similar to a forensic investigator where by means of the skid marks, and type of pavement he can estimate the vehicle speed [8].

Speed Calculations for Traffic Accidents" – SCTA - software

The SCTA software was developed, by teachers and researchers from a Federal University from Brazil, using the Delphi language, and its purpose is to simulate the driver's initial speed in some traffic accident scenes (uphill terrain, sloping terrain, flat terrain, two types of lane stretches, etc.). According to the authors´ model, the driver steps on the brake when he sees a stopped obstacle, and after the collision the car comes to rest. In this simulator, the friction coefficient (correlated with the type of pavement), the skid distance, in the case of terrains on an uphill and/or sloping ground, the angle formed with the horizontal and the speed of damage are input parameters. The output parameter is always the estimated initial speed of the vehicle when the driver steps on the brake with a tolerance of 10%. Speed of damage is the vehicle speeds that causes some kind of damage during crash tests, and are associated to the kinetic energy lost due to collision [9]. The value to be entered in the vehicle damage speed can also be consulted in a table presented in SCTA software, where the damages are evaluated according to the intensity of their damages and to the physical characteristics of the moving vehicle. The ones presented in the software table can be used in a generic way, when there is no more detailed data about the vehicle involved.

Physical Model

According to [8], the theoretical model (no collision) considers a car traveling on a plane at a speed Vi, which collides with a wall or with another car. After applying the brakes, the car skids over the road, and the kinetic friction force is the only net force in the direction of motion:

a=acceleration
μ=coefficient of friction
g=acceleration due to gravity
Vf=speed after skidding
df=skid path
Vfren=braking speed

$$F_R = m.a$$
$$a = -\mu.g$$

$$V_f^2 = V_{fren}^2 + 2.a.d_f$$

Vi=initial speed before braking

Since Vf=0 in the collision, we have: $V_{fren} = \sqrt{2.a.d_f} = \sqrt{2.\mu.g.d_f}$

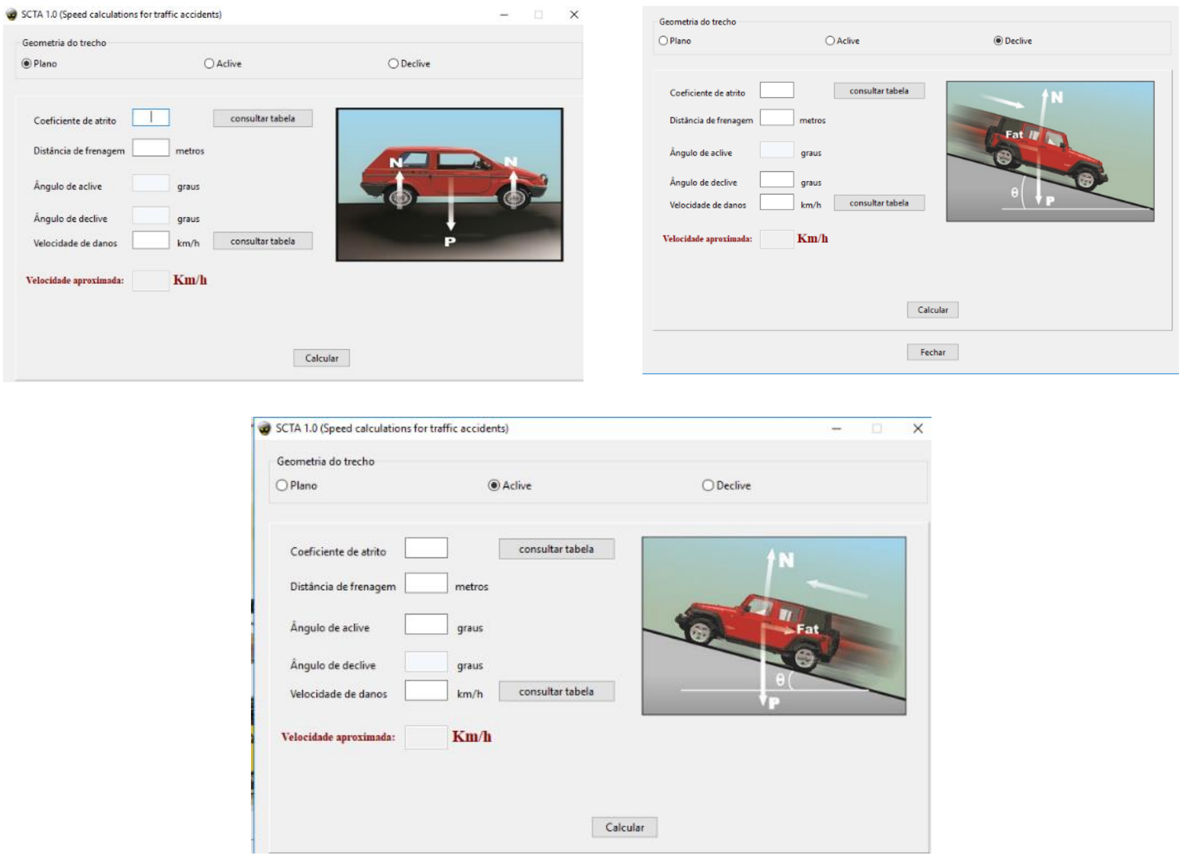
In the collision´s situation with an object at rest (for example a car on the plane collides with another one stopped at the light) we have to consider that after applying the brakes, the car skids on the track, and kinetic friction force is assumed to be constant and it is the only resultant force in the direction of the movement. Assuming that the car before colliding with the object was braked, and after collision it stops, the energy balance is performed. The dissipated energy ($E_{dissipated}$) will be equal to the lost energy by friction (W_{fat}) and the kinetic energy associated to the damage caused to the car after the collision (W_{damage}), since final system energy is null.

$$E_{initial} = E_{dissipated} = W_{fat} + W_{damage} \qquad \frac{1}{2}.m.V_i^2 = \frac{1}{2}.m.V_{fren}^2 + \frac{1}{2}.m.V_d^2$$

So, $V_i = \sqrt{V_{fren}^2 + V_d^2} = \sqrt{2.\mu.g.d_f + V_d^2}$

Figure 1 shows examples of the interface between the software and the user.

Figure 1 – SCTA software interface



Applied Physics Seminars - using a simulator software "Speed Calculations for Traffic Accidents" – SCTA

In the Physics laboratory, students are divided into teams (usually compounded by 3 or 4 students each), teachers raffle one case for each team (uphill terrain, sloping terrain, flat terrain, two types of lane stretch) and students must:

0) Read the original paper about "Speed Calculations for Traffic Accidents" [8] and pay attention for general teacher's explanation during class laboratory and download of SCTA software
1) Use Design Thinking methodology for project planner [10],[11]
2) Do Physical modeling of the phenomenon trying to extend the model that was presented in the original paper
3) Use the evaluation laboratory (Open LMS) analyzing the proposal of another team under three aspects: a) were the data filled in correctly? b) Is the immersion stage organized? and c) Was the modeling adequate?
4) Do simulations and check model's validity (by means of graphic analysis and comparing the fitted curves to the model predictions), and
5) Prepare a presentation about the selected traffic accident scene, explaining the model from original paper, and presenting their graphic analysis as well.

In this way, through a contextualized problem, we intend to develop physics modeling competencies and soft-skills like teamwork and oral and written communication skills. Their final presentations (10 minutes) were performed to the whole class and they were evaluated by rubrics [12], [13], [14]. After presentation end, teachers showed to each team, the good points and the points that had to be improved.

Design Thinking methodology for project planning

The Design Thinking stage [10], [11] is carried out in class. All other work preparation is outside class, with the final assessment (presentation) being performed in a face to face class.

In the Design Thinking stage, the team must perform the following tasks in order to organize the development of the activity:

1) To identify the drawn case
2) To identify the input parameters in the software
3) To define which analyses will be performed and which parameters must be either fixed or variable
4) To define which graphics should be prepared
5) To choose two different situations and to compare them
6) To check if they have all the necessary information to develop the project (for example, when analyzing uphill or downhill, the student must consider that it is not physically possible to set any angle. In real case, there is a maximum practical angle that can be used. This angle often is legally regulated in technical engineering standards)

Considerations regarding modeling and graphical analysis

As it can be seen from the modeling, the initial velocity depends on the variables (coefficient of friction, distance, velocity of damage), but the equation is of the root type, so the student may have difficulty analyzing the relationship between the variables if he chooses data where the curve is located on a linear region. This was a good opportunity to teach graph linearization, by instructing them to construct graphs of square initial velocity as function of stopping distance or friction coefficient, or initial velocity as function of square damage velocity. The team after fitting the curve and obtaining the equation by using Excel, should find the correlation between the fitted curve and the physical model: $V_i^2 = 2.\mu.g.d_f + V_d^2$. This is an interesting discussion to be held with the class.

It was observed that students often don´t draw up all possible graphs. So, it´s important to reinforce that sensitivity variable analysis is fundamental for the development of a physical model.

Presentation of modeling and analysis

Students must follow this script in the presentation:

- Presentation of the theme
- Analyzed problem (drawn case study)
- Modeling
- Simulations performed and methodology (explain which parameters were used and why)
- Graphs and analytics
- Comparison with another case of free choice (explain which parameters were used and why)
- Conclusions

2022 Rubrics applied

Using the competence-based assessment proposal [14], [15], [16], [17], in 2022, the following rubrics were used and disclosed in advance to students.

Were the objectives clear?	Highlighted position Objectives were quite well described 4 points	Proficient – They were only exposed 3 points	Learning not clearly defined 2points	Beginner – not stated clearly the objectives 1point	Didn´t do anything at all. 0points
Were the seminar didactic?	Highlighted position - Well organized. The team contributed with detailed and new information to class. 4 points	Proficient - well organized 3 points	Learning Reasonably organized 2points	Beginner - Very messy. Not clear point of view 1point	Didn´t do anything at all. 0points
Were all the solicited tasks executed?	Highlighted position	Proficient	Learning About 50% of the tasks	Beginner –	Didn´t do at all. 0points

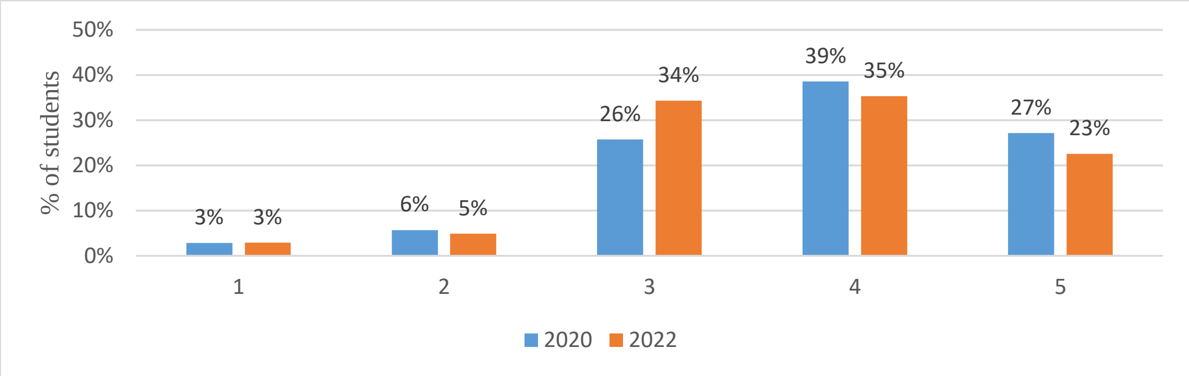
	All tasks were executed pretty well. 4points	About 80% of tasks were performed well. 3points	were performed well. 2points	Many tasks were not presented. 1point	
Did the students show capacity of solving problems?	Highlighted position The team showed all the calculations, showing knowledge about the involved concepts. The hypothesis and Physics laws were well described in the model. 4points	Proficient Good analysis with some minor conceptual errors 3points	Learning Bare analysis. Students didn´t show the necessary deepness about the theme. 2points	Beginner – Many errors in equations. Difficulties in Graphic analysis. 1point	Didn´t do anything at all. 0points
How was the oral communication?	Highlighted position The team showed knowledge about the selected theme and performed pretty well in answering the questions. 4points	Proficient Good presentation, but students had some difficulties in performing oral communication. 3points	Learning Students had difficulties in performing oral presentation. Some important conceptual errors were made. 2points	Beginner – Not clear presentation. Many errors. 1point	Didn´t do anything at all. 0points

So, the final grade is obtained by averaging the grades obtained in each indicator.

Results

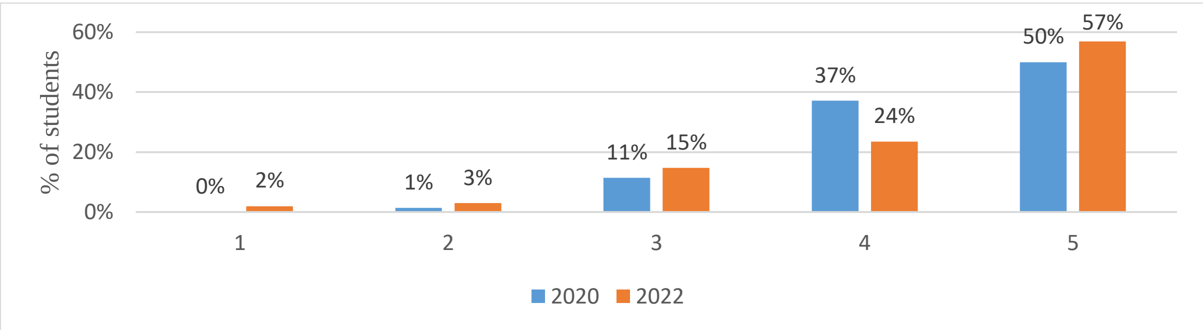
In order to verify the students' perception regarding the development of the project, a survey was used, which comprised of 5-point Likert-scale items ranging from ‘strongly agree’ (5) to ‘strongly disagree’ (1). The survey items asked students to respond about their attitudes, team work, project manager and learnings. In 2020, the Applied Physics Seminars was applied to a universe of 600 students, and get 70 responses (nearly 12%). In 2021, during pandemic, the project was not evaluated. In 2022, in a universe of 424 students, get 103 responses (nearly 24%). Then, the analyses referring to each question are presented.

Question 1: On a scale of 1 to 5, where 1 is "not at all interesting" and 5 is "very interesting". How do you rate the theme of the project?



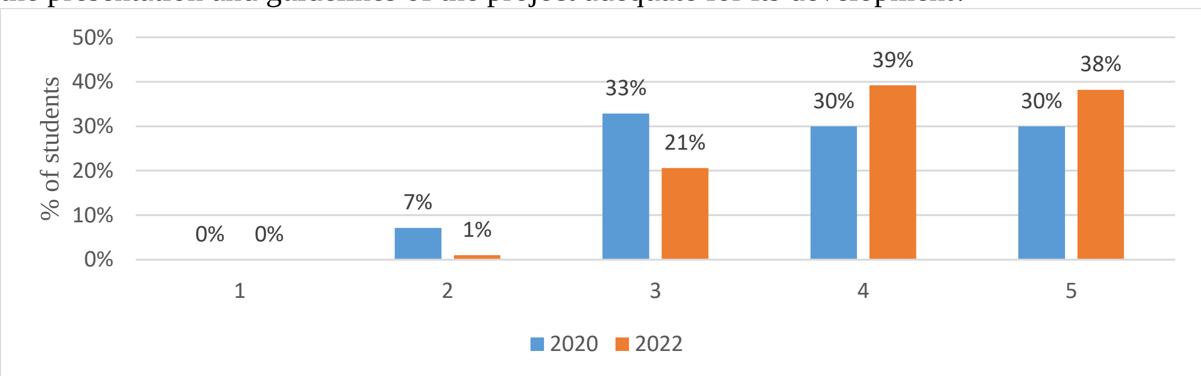
It´s possible see that in 2020 more than 66% of students found the topic very interesting (grades 4 and 5). In 2022, it was 58%. The results showed that the subject is suitable for applying with undergraduated engineering students, generating motivation to study the concepts of Newton Second Law, Energy and Collision.

Question 2: On a scale of 1 to 5, where 1 is "no" and 5 is "yes". Was the time for completion adequate?



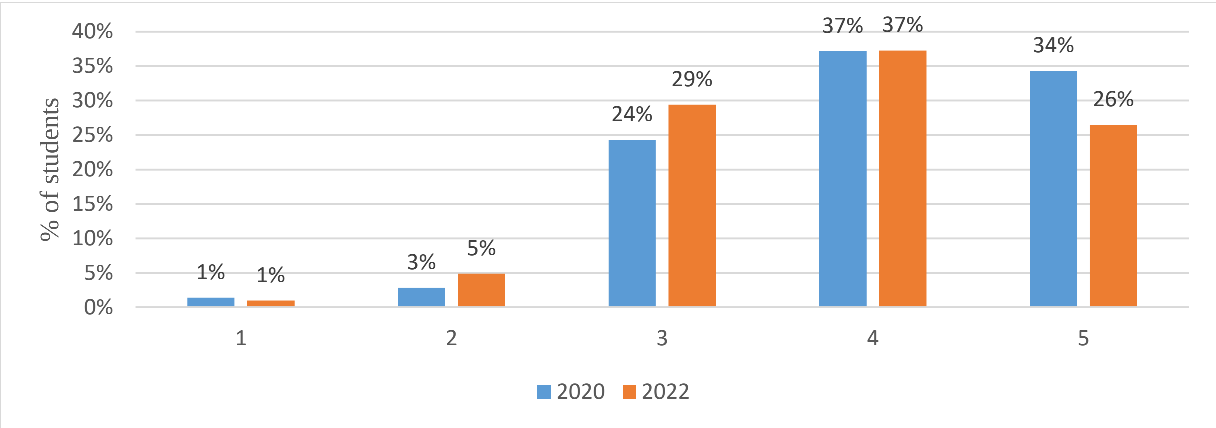
In 2020, 87% of students (grades 4 and 5) felt the time was adequate to carry it out, in 2022, 81%. The results showed that the time (about 15 days) is suitable for submitting the complete activity.

Question 3: On a scale of 1 to 5, where 1 is "not adequate" and 5 "completely adequate". Were the presentation and guidelines of the project adequate for its development?



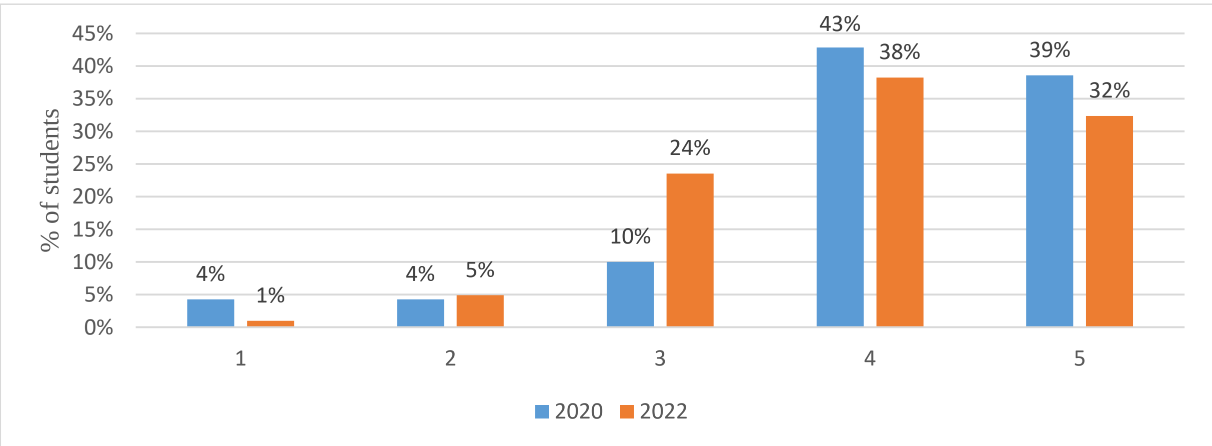
In 2020, 60% of students (grades 4 e 5) found the guidelines for the project adequate, in 2022 77%. This percentage increased, in 2022, probably due to greater attention to the design thinking phase promoted by the use of the evaluation laboratory.

Question 4: On a scale of 1 to 5, where 1 is "didn't help at all" and 5 "significantly helped". Did the rubrics that assess certain dimensions and their levels of performance help me better prepare the work?

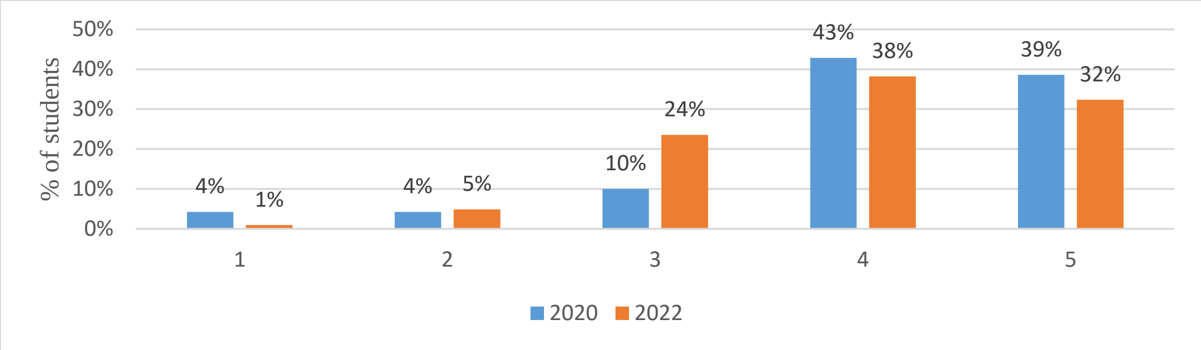


In 2020, for 71% of students (grades 4 and 5) the previous presentation of the rubrics helped them to better prepare the work. In 2022, about 63%, most probably because in 2020 the rubrics were used only at the end of the semester with the seminars, and in the current year, the rubrics were used during the whole year since the first task that was delivered in group.

Question 5: On a scale of 1 to 5, where 1 is "did not help at all" and 5 "helped significantly". Do you consider that the project brought you further information? Did you improve your understanding of the contents taught in theoretical classes?



Question 6: On a scale of 1 to 5, where 1 is "I didn't see any relationship with Engineering" and 5 "I saw a great relationship with Engineering applications". Do you believe that the project brought you information about applications in Engineering?



Analyzing graphs of question 5 and question 6: in 2020, 82% of the students (grade 4 and 5) believed the project improved the understanding of the theory and presented applications involving physics applied to engineering. In 2022, 70%. In both years there is a low difference between the students that correlated the seminars to taught and students that believe to have learned new applications with the seminars. Most probably this difference can be associated to the student´s profile changes.

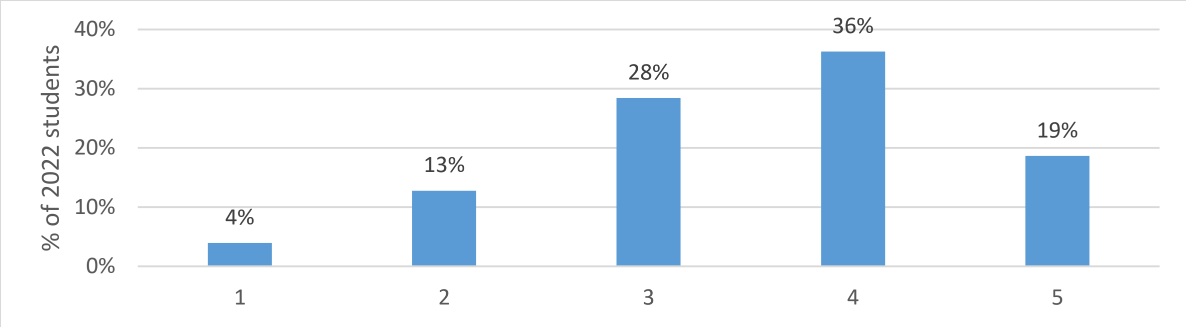
One remarkable point about these changes is that the students of 2020 had the first year of the engineering course on line, but the previous year their senior high school was 100% presential; in contraposition, the 2022 first year student had two years of their senior high school online and the first year of engineering course completely presential. Thus, they had the opportunity to have their lab classes and other activities in a presential mode. Thus, their expectations about theory application are a little different, decreasing from 82% to 70% from one year to another.

In 2022, the "evaluation laboratory" tool of Open LMS was added to the project in design thinking methodology step. Using this tool, students can submit the initial seminar planning to be evaluated by teachers and at the same time do peer review of other groups activities [18], [19], [20]. They can ask questions and made reflections about other groups activities so developing critical thinking during this process before submitting the final seminar presentation.

The "evaluation laboratory" tool consists of a peer evaluation mechanism, enabling, in addition to sending open feedback, through suggestions, the elaboration of parameters for work evaluation (structured feedback). This resource can also contribute to issues related to interpretation skills, critical analysis and the writing process, influencing the student's interaction with the digital environment in a collaborative way.

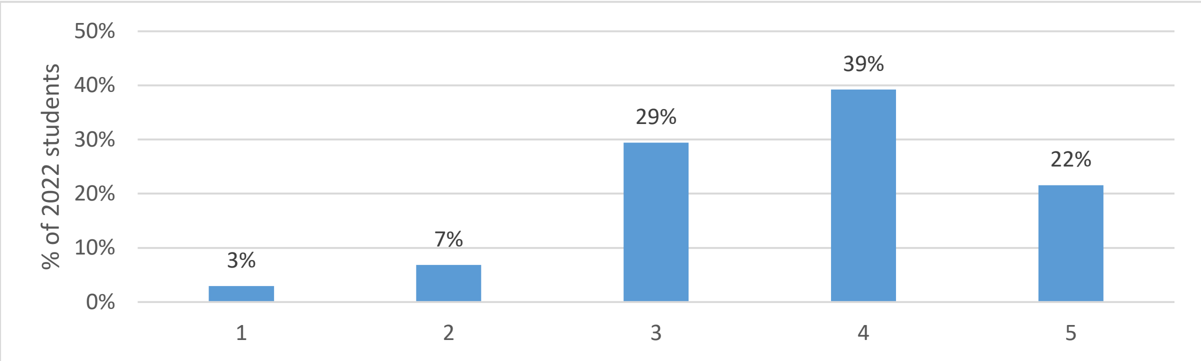
In the proposed activity, this resource was applied in the design thinking structured elaboration phase where they project the tasks that must be done. This practice aimed to contribute to aspects related to clarity, objectivity and interpretation of the research problem, since these parameters were examined by colleagues. In the evaluation phase, the research question was analyzed, firstly, online by other students and, secondly, by teacher, to assess the veracity of the initial interpretation carried out through digital writing.

Question 7: Considering the use of "evaluation laboratory" tool, where your team had the opportunity to contribute to the work of other colleagues. On a scale of 1 to 5, where 1 is "did not help at all" and 5 "helped significantly". Do you think peer observations helped you?



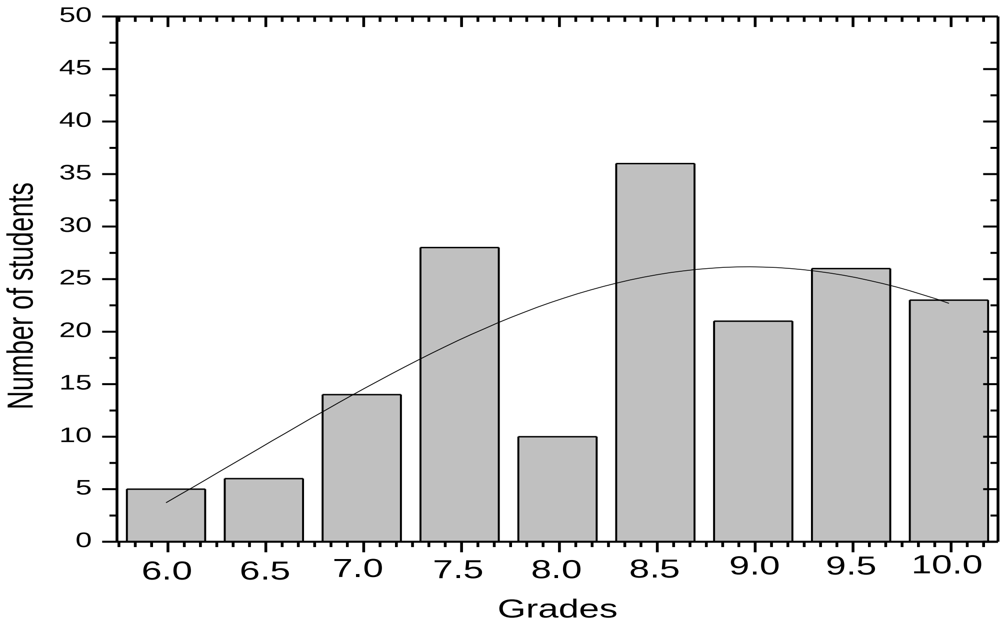
According to this graph about 55% (grade 4 or 5) considered peer observations helped them in the design thinking step.

Question 8: Considering the use of “evaluation laboratory” tool, where your team had the opportunity to contribute to the work of other colleagues. On a scale of 1 to 5, where 1 is "did not help at all" and 5 "helped significantly". Do you think that by correcting the work of other colleagues, it helped you to develop a critical spirit?



For almost 55% of the students (grades 4 and 5), peer observations helped their preparation process, and for 61% contribute to develop a critical spirit. This a quite interesting result, they feel they learned more during the correstions they had to do at their colleagues activities.The comparison betwee what they were doing and what they colleagues proposed to do helped them improving their work.

The graph below shows the distribution of final grades obtained by students in 2022. It can be seen that of the 179 student´s presentation delivered, 82% (146) achieved grades based on rubrics above 7.5.



The Gaussian function was fitted to the obtained grades showing the distribution is slightly skewed. The Pearson´s coefficient of skewness # 1 is equal to -0.51, this negative coefficient is a relation between the media value and the mode (the most frequent grade). The higher incidence of grades superior to 9.0 shows us the team work efficacy where students that have a better comprehension of the studied subjects can help the ones with more difficulties resulting in good grades for all. There are few groups of students (about 5 students) with grades lower than 6.0, most probably due to the fact they prepared the seminar in a hurry, submitting something just trying to avoid getting zero. However, the average grade and standard deviation was about (8.3$\pm$0.5), showing the students were completely engaged.

In general, it appears that the project attended to the expectations, resulting in a better academic achievement and the development of the desired competences and skills.

Among the teachers' comments on the papers presented, the following stand out:

“Be careful with the titles of the charts... Make your comparison clearer. It was necessary to talk about energy modeling to obtain the expression used.”
“Excellent presentation! The slides are very clear and well organized. All analysis steps were done properly. In particular, the comparison made at the end was a great way to conclude the presentation.”
“There was a lack of adjustment to the trend line and a physical explanation for the adjustments.”
“Overall, the presentation was very good and didactic. As we discussed earlier, it would have been important to start with a slightly more detailed (but not long) theoretical introduction to the subject. There was a small problem in the final part of the modeling. The term Vdamage should have been included in the final expression obtained. In the case of the constructed graph, first, do not forget to place the measurement units of the magnitudes on the axes. Furthermore, it would have been important to fit a function to the graph and interpret the parameters determined for such a function.”
“Overall, the performance was great. The slides are well organized and all analysis steps have been done. As we discussed on the day of the presentation, just be careful with the graphics you build. Do not forget to place the units of measurement of the magnitudes on the axes.”

There is a need to reinforce some details, but in general, the presentations were satisfactory.

Final considerations

The development of applied Physics activities aimed at developing competences and skills that must be constantly assimilated by the students and the teacher staff so that it can be worked on properly. Initial planning using methodologies such as Design Thinking and peer review provided adequate evidence to allow better organization of activities and ideas related to the modeling process. Applied Physics Seminars - using a simulator software seems a good way to promote physical modeling competences.

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