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Modeling the Movement: A Challenge-Based Learning Course for Engineering Students

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Modeling the Movement: A Challenge-Based Learning Course for Engineering Students

Abstract

Universities face challenges such as integrating a globalized world, the need for new competencies in the job market, new educational models, and technological advances that create societal concerns regarding traditional higher education. During the last few years, our institution, a large private multi-campus Mexican university, has been preparing for these new challenges changing the educational model from a traditional lecture-based to challenge-based learning with an emphasis on competency development. Entering the School of Engineering and Sciences, first-year students take the Modeling the Movement course, with the primary objective of introducing students to Newton's laws of motion from an interdisciplinary perspective that combines physics, mathematics, and computer science. We surveyed 533 students enrolled in the course. We present the course design, focusing on the challenge-based approach and interdisciplinarity. We report an overview of student satisfaction based on the achievement of competency development, the student's perception of the importance of physics, mathematics, and computer science in their professional practice, and their perceptions of difficulty and time demands. The overall results of the survey show a high level of student satisfaction. The students perceive that with the course, they developed the disciplinary and transversal competencies declared in the course objectives. They value the relevance of physics, mathematics, and computer science as an interdisciplinary aspect of the course and their professional practice. Their perception of difficulty and time demands is neutral.

Keywords: challenge-based learning, higher education, educational innovation, competency development, interdisciplinarity, physics education.

Introduction

Universities face the challenges of an integrated, globalized world, which have created the need for educational models based on competency development. Our institution, a private multi-campus Mexican university, faces these challenges by migrating the traditional, lecture-based educational model to a challenge-based learning methodology emphasizing competency development instead of content knowledge acquisition [1]. Under the new educational model, the curricular structure of undergraduate programs consists of three phases: exploration, focus, and specialization. While in the exploration phase (the first two or three semesters), academic programs in the same area have a core curriculum. This means that the programs related to the School of Engineering and Sciences share the same curriculum for the first three semesters, allowing students to shift smoothly from one area to another.

All the School of Engineering and Sciences students take the Modeling the Movement course in their first semester. It is the students' first interdisciplinary Challenge-Based Learning (CBL) course. The model integrates CBL [2, 3], the How People Learn (HPL) framework [4], and the Legacy Cycle [5]. The HPL framework establishes four interrelated attributes in learning environments: the focus on the learners (their preconceived knowledge, skills, and attitudes), the attention to what is taught, why it is taught, and what competencies are required (learning with understanding), the importance of formative assessments, and the influence of the context in which learning takes place. In this educational model, the challenges have three main characteristics: a) For students, the challenge should be relevant and simulate an actual situation in the professional field they are pursuing; b) Through the solution, students develop the desired level of competency mastery, and c) students should realize that to generate a solution, they need the disciplinary knowledge provided in the course. Our educational model delivers this in what we call a learning block [1].

In this contribution, we present the design of the Modeling the Movement courses as the context of this study. We describe the methodology and report an overview of students' perception of the course in general, each of the modules, and the challenge. We discuss the results highlighting the affordances of the course design and the areas for improvement.

Context of the study

Our institution is a multi-campus private university with 25 campuses in Mexico. The School of Engineering and Sciences is the largest school at the university, offering 18 undergraduate academic programs in four sub-areas of engineering referred to institutionally as *avenues*: Bioengineering and Chemical Process (BCP), Innovation and Transformation (IT), Computer Science and Information Technologies (CSIT), and Applied Sciences (AS). The total undergraduate enrollment of the school is 24,000 students.

The School of Engineering and Sciences' Modeling the Movement courses introduce engineering students to Newton's laws of motion with an interdisciplinary approach that combines physics, math, and computing. Each avenue offers a Modeling the Movement course oriented towards applying Newton's laws in the avenue's context. For example, the BCP avenue offers the course "Motion Modeling in Bioengineering and Chemical Processes." With a challenge-based learning strategy, students develop engineering and transversal competencies, learn the disciplinary content of Newton's laws in the avenue's context, see close-to-practice professional applications of challenge solutions, and understand the importance of the avenue's contribution to technological development in society. Each Modeling the Movement course approaches its objectives through four disciplinary modules (one for math, one for computing, and two for physics) and one module for the challenge solution, delivered in 5 weeks. Every week, the students dedicate 12 hours to the course; some weeks, they have a higher load of mathematics, computing, or physics, and others a higher load for the challenge solution and evaluation.

All Modeling the Movement courses have the same module organization, as presented in Table 1: 10 hours for the math module, 10 hours for the computing module, 12 hours for each of the physics modules, and 16 hours in sessions focused on working on the challenge. During the first four weeks, students spend 10 hours per week on modules and 2 hours on the challenge. In the course's final week, students spend 4 hours on modules and 8 hours on the challenge.

Table 1. Organization of modules in the Modeling the Movement course throughout the 5-week duration.

	Week 1	Week 2	Week 3	Week 4	Week 5
2 hrs	Mathematics module	Mathematics module	Mathematics module	Computing module	Computing module
2 hrs	Mathematics module	Mathematics module	Computing module	Computing module	Computing module
2 hrs	Kinematics module	Kinematics module	Dynamics module	Dynamics module	Challenge
2 hrs	Kinematics module	Kinematics module	Dynamics module	Dynamics module	Challenge
2 hrs	Kinematics module	Kinematics module	Dynamics module	Dynamics module	Challenge
2 hrs	Challenge	Challenge	Challenge	Challenge	Challenge

The challenges in all Modeling the Movement courses in the School of Engineering and Sciences follow a similar design. The main characteristics of a challenge are that they are based on a real-life scenario or close to the work life and that they integrate content knowledge from all the different modules to be solved. The organization of the challenge as two hours per week during the first four weeks and 8 hours in the last week allow students to focus on the steps needed to solve the challenge and organize their time effectively. In addition, every challenge requires students to learn disciplinary knowledge from the avenue to solve it, so students are expected to become aware of the link between content knowledge and its application in real life. Student assessment may vary from one course to another. However, in general, students' challenge solutions are assessed with either an oral presentation, written report, or video that serves as evidence of competency development. A written or oral argumentative examination is also commonly used as evidence of competency development. Additionally, in-class activities and tests assess their participation in the course modules.

In the "Motion Modeling in Engineering" course (IT avenue), the most widely used challenge has students analyze a steering system for an autonomous vehicle based on a rack and pinion mechanism. In this challenge, students analyze the conversion of the angular motion of the steering wheel into the linear movement of the rack, as well as from the linear motion of the rack into the angular motion of the wheel as it steers, and generate a computer simulation using Matlab that displays the motion of the rack and pinion system as well as that of the vehicle.

In the "Computational Modeling of Movement" course (CSIT avenue), the most widely used challenge has students develop an engine that randomly generates 2D visualization of projectiles ejected from a volcano. In this challenge, students create a computer simulation using Matlab that displays the motion of the projectiles as well as the values of kinematical variables of interest.

Methodology

We measured students' perception of the “Modeling the Movement” course concerning achieving objectives, their perceived value of each module and challenge, and meeting time demands. The study consisted of an online survey for first-semester engineering students. We surveyed 4,600 students enrolled in the “Modeling the Movement” course nationwide in September 2022 using the Qualtrics survey tool. We received responses from 533 voluntary participants (12%).

The survey consisted of 38 Likert-scale items with five levels, ranging from Strongly Disagree to Strongly Agree. We grouped the survey items into five dimensions: General perception of the course, Perceived achievement of objectives, Perceived value of module’s content, Perceived value of solving the challenge, and Perceived Demand. The “General perception of the course” dimension asked students if the whole course focused on working on specific abilities and learning more about Physics than in traditional classes (4 items). The “Perceived achievement of objectives” dimension asked students if they considered achieving each module's declared objectives related to learning disciplinary content and developing engineering and transversal competencies (9 items). The “Perceived value of module’s content” dimension asked students whether the topics of each module were necessary for solving the challenge and were interesting (6 items). The “Perceived value of solving the challenge” dimension asked students whether solving the challenge allowed them to see or understand specific aspects differently and to value the challenge in terms of interest, motivation, and gratification (11 items). The “Perceived Demand” dimension asked students their perception of time demand and difficulty of the topics covered (8 items).

Results

We quantitatively analyzed the Likert data and frequency levels as ordinal variables to calculate the percentages. Additionally, we assigned values to the scale, ranging from 1 (Strongly disagree) to 5 (Strongly agree), to compute the mean as a statistical indicator. The computation of the mean assumes the Likert and frequency levels are interval variables, but we recognize that the participants may not perceive the scale as evenly distributed. The results section presents the results in 5 subsections, one for each dimension. Every subsection first presents a table summarizing the mean of each item and a figure showing the percentage of students in each level of the Likert scale for every item. All the figures use light traffic colors: the rates of the students who agreed and strongly agreed in soft and dark green, the students with the neutral answer in yellow, and the students who disagreed and strongly disagreed in orange and red, respectively. This format is used evenly throughout the study.

The general perception of the course

Four items assess students' perception of their general achievement in the Modeling the Movement course: (1) Using objective and reliable methods, (2) Solving complex problems, (3) Arguing using Physics principles, and (4) Learning more of Physics compared to a traditional course. Table 2 presents the calculated mean for each item and module. We observe that the mean of three things is higher than 4, implying that the students perceived they satisfactorily learned to use objective and reliable methods, solve complex problems, and argue using Physics principles. The mean for learning more about Physics compared to a traditional course was 3.65.

Table 2. Calculated mean of student perception of achievement in the course.

Achievement	Mean
Use objective and reliable methods	4.29
Solve complex problems	4.26
The argument using Physics principles	4.30
Learn more about Physics compared to a traditional course	3.65

Figure 1 presents the percentages of students by agreement or disagreement with each item and module. The median of all items is in the "Agree" level, which indicates positive results. In items (1), (2), and (3), the student's perception of their achievement was over 80%. Between 10% and 15% of the students felt neutral about their achievement, and less than 10% of students presented a negative perception. Item (4) shows a different trend. Roughly 60% of students presented a positive perception, more than 20% were neutral, and less than 20% gave a negative perception. These results imply that students largely perceived that they achieved the general goals of the Modeling the Movement course. However, not all students perceive that they learn more about physics with this course than traditional courses, like the ones they took in their preparatory education. This means that students do not necessarily perceive they know more about Physics using challenge-based learning instead of traditional teaching, which could be linked with an overall resistance to changing the educational model.

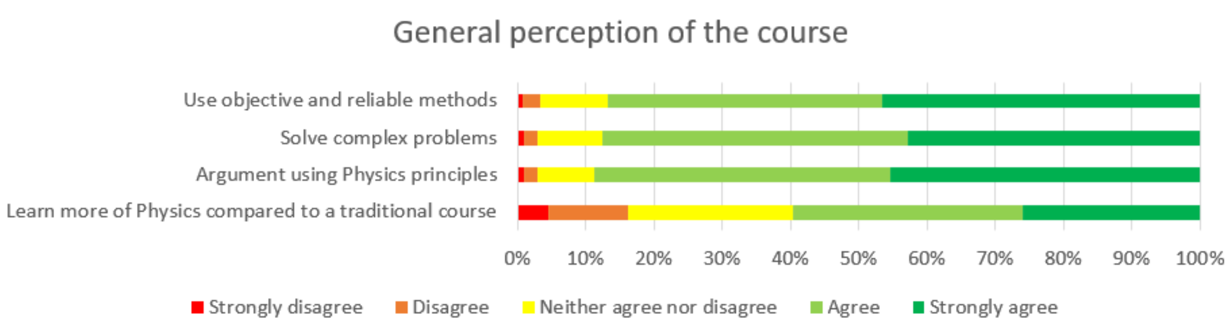

Figure 1. Percentage of student perception of achievement in the course.

Perceived achievement of objectives

Three items assess students' perception of their achievement of the objectives in the Modeling the Movement course: (1) Learning disciplinary content, (2) Developing engineering competency, and (3) Developing transversal competency. Table 3 presents the calculated mean for each item and module. We observe that the mean of most items is higher than 4, implying that the students perceived they satisfactorily achieved the Modeling the Movement course objectives.

Table 3. Calculated mean of student satisfaction for objective achievement for each module.

Objective	Math	Computing	Physics
Learning disciplinary content	4.22	3.95	4.27
Developing engineering competency	4.26	4.14	4.30
Developing transversal competency	4.20	4.13	4.26

Figure 2 presents the percentages of students by agreement or disagreement with each item and module. The median of all items is in the "Agree" level, which indicates positive results. The students' perception of achieving objectives was over 80% across the six items of the Math and Physics modules. In the computing items, it was over 80% for developing engineering and transversal competencies and over 70% for learning disciplinary content. Between 10% and 15% of the students consistently felt neutral about achieving objectives across the items and modules. Less than 10% of students felt dissatisfaction with all the items and modules. These results imply that students largely perceived that they achieved the objectives of the Modeling the Movement courses offered by the School of Engineering and Sciences.

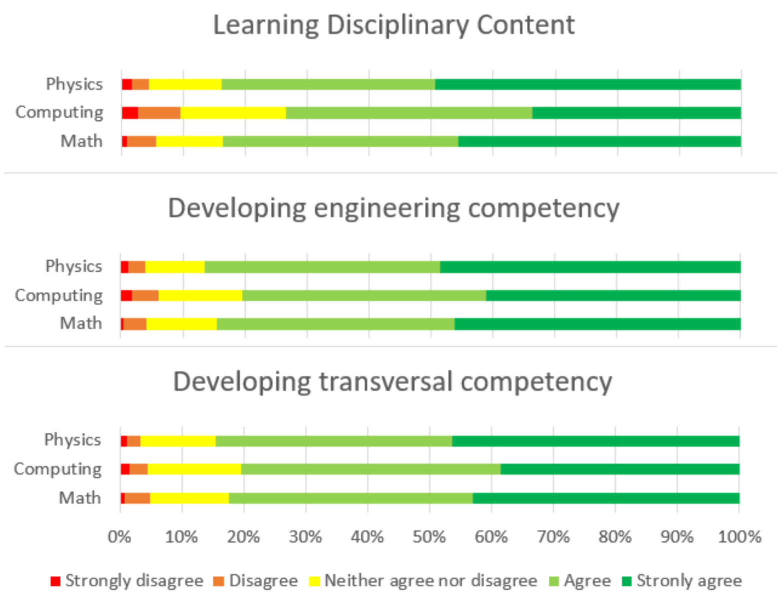

Figure 2. Percentage of student satisfaction for objectives achievement in each module.

The perceived value of the module's content

Two items asked students' perception of the content of the math, computing, and physics modules: (1) If the topics covered are necessary for solving the challenge, and (2) If the topics are interesting. Table 4 presents the calculated mean for each item and module. We observe that the mean of all items is higher than 4, implying that the students perceived that the contents of each module were valuable for solving the challenge and interesting.

Table 4. Calculated mean of students' perceived value of the module's content.

Aspect	Math	Computing	Physics
Necessary content for solving the challenge	4.03	4.21	4.44
The topics are interesting	4.07	4.05	4.27

Figure 3 presents the percentages of students by agreement or disagreement with each item and module. The median of all items is in the "Agree" and "Strongly agree" levels, which indicates positive results. The student's perception of the value of the modules was over 75% across all items. The Math and Computing modules follow similar trends. Between 75% and 85% of students agree that the topics are interesting and necessary for solving the challenge, around 15% feel neutral, and less than 10% disagree. The students perceived the Physics modules more positively; over 80% found the topics interesting, and over 90% found them necessary for solving the challenge. Essentially, students perceived that the topics covered in all the modules were necessary for solving the challenge and were interesting. However, this perception is amplified for the physics modules.

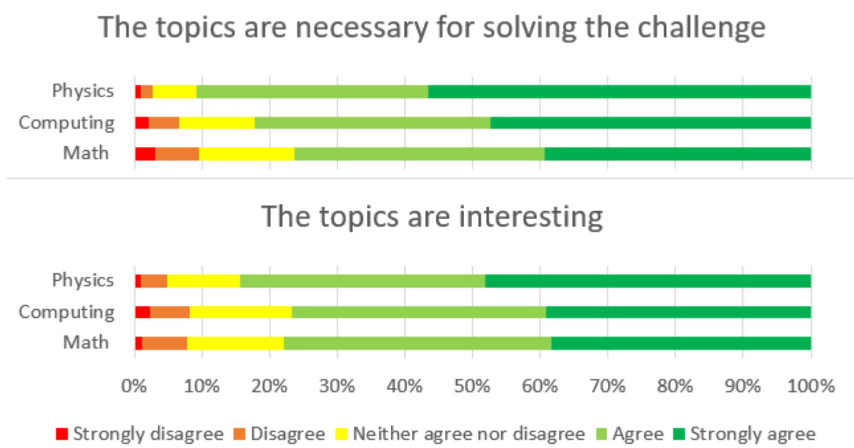

Figure 3. Percentage of students' perceived value of the module's content.

The perceived value of solving the challenge

Eleven items asked students' perception of the value of solving the challenge in two main parts: (1) What the challenge allowed students to see, understand, or develop (8 items), and (2) If solving the challenge was motivating, gratifying or interesting (3 items). Table 5 presents the calculated mean for each item. We observe that the mean of most items is higher than 4, implying that the students positively valued the experience of solving the challenge and the challenge itself. Only two items presented a mean below 4: If solving the challenge allowed students to know the work field better (3.88) and if they found solving the challenge a gratifying experience (3.84).

Table 5. Calculated mean of students' perceived value of solving the challenge.

Solving the challenge allowed…	**Mean**
Solve complex problems	4.18
Use computational tools	4.10
Understand the applications of math	4.00
Understand physics concepts better	4.00
Understand the relationship between physics, math, and computing	4.33
Understand the relevance of physics, math, and computing	4.18
Get to know the work field	3.88
Understand the challenges in this model	4.22
Solving the challenge was…	**Mean**
Motivating	4.23
Gratifying	3.84
Interesting	4.00

Figure 4 presents the percentages of students by agreement or disagreement with each item. The median of all items is in the "Agree" level, which indicates positive results. Over 80% of students agreed that solving the challenge was motivating and allowed them to solve complex problems, use computational tools, understand the relation and relevance of physics, math, and computing, and understand how challenges are presented in the challenge-based educational model. Over 70% of students agreed that solving the challenge was gratifying or interesting. It allowed them to understand better the applications of math and the concepts of physics and get to know the work field. Around 10% and 15% of students feel neutral about the experience of solving the challenge, and less than 10% perceived it negatively in most items. The items with more disagreement were that the challenge allowed students to get to know the work field better (13%) and that solving the challenge was gratifying (14%). Overall, students sometimes perceive the experience of solving the challenge positively and neutrally. In this case, it is noteworthy that the challenges are designed to correspond with the interest of the different avenues. However, small campuses offer only one of the avenues so that students can perceive a mismatch between their interests and the challenge provided to them.

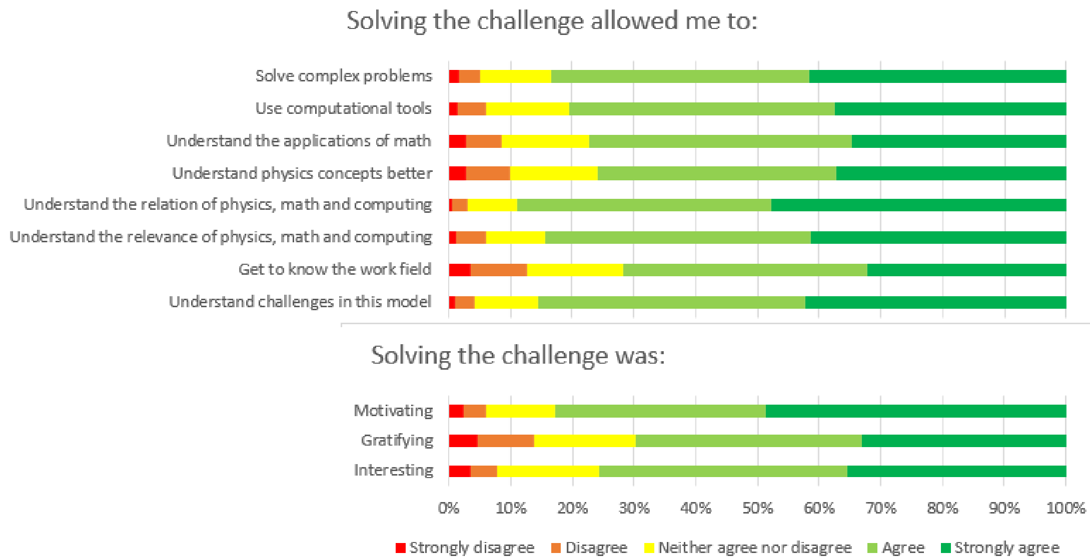

Figure 4. Percentage of students' perceived value of solving the challenge.

Perceived Demand

Two items assessing students' perception of the time and difficulty that the course demanded each module and the challenge. Table 6 presents the mean for each item and module, and Figure 5 shows the percentage of student perception for each item. These items had a negative load, so the preferred outcome should be disagreement, numerically closer to 1 than 5. Therefore, the traffic-light colors are inverted in Figure 5. We observe in Table 6 that the mean of student perception of both difficulty and time demand is smaller than the arithmetic mean of the scale (3.00) for the math and computing modules. The perception of difficulty and time demand for the Physics modules and the challenge is close to the arithmetic mean, meaning students find this module's demands as neutral. In Figure 5, we observe that the median time demand for math and computing and of the perceived difficulty in the math module disagree, confirming that students feel that these modules' difficulty and time demand is low. The remaining medians are 3, ensuring students feel neutral about the modules' and challenges' difficulties and time demands.

Table 6. Calculated mean of student perception of difficulty and time demanded.

Demand	Math	Computing	Physics	Challenge
Perceived difficulty	2.60	2.77	2.85	3.03
Perceived time demand	2.53	2.59	3.04	3.39

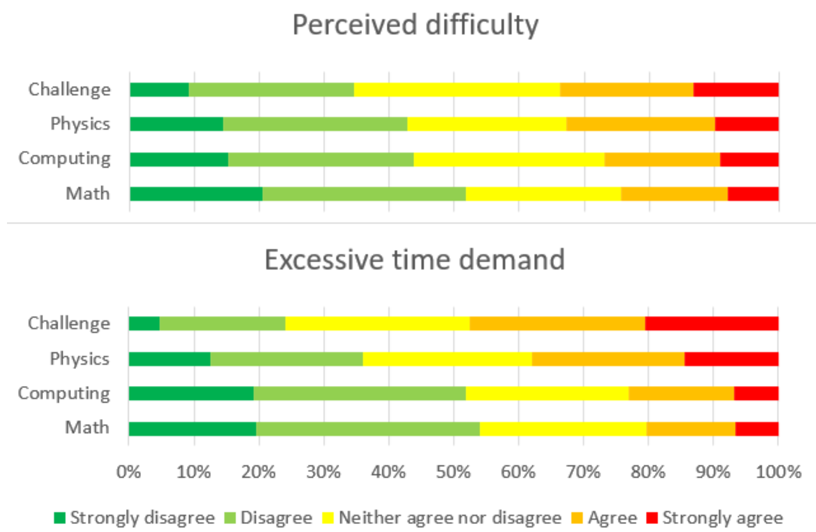

Figure 5. Percentage of student perception of difficulty and if the time demanded was excessive.

Discussion

The results show positive student satisfaction regarding the achievement of objectives of the course in general and in each module. Moreover, the experience of solving the challenge was overall positive, but it still has room for improvement. In this section, we discuss some of the findings of this study, focusing on the items that follow different trends and recognizing the affordances of the course design and the room for improvement whenever possible.
In the items that evaluated the general perception of the course, the item where students compare their physics learning in this course with traditional courses stands out. From this result, we interpret that students have paradigms formed by traditional classes about how to learn physics [6]. In their previous education, students would learn physics by learning and applying formulas to solve textbook problems. In this course, students had to use their physics knowledge to solve a challenge they presumably had never encountered.

Another tendency that stood out from our results was that students perceived they learned less disciplinary content in the computing module than in the physics and math modules. This could be due to students considering computing content knowledge as a tool rather than as disciplinary content. As Chabay and Sherwood had previously pointed out [7], introducing computing in the introductory physics course only makes sense if it supports the course objectives. When asking students about the perceived value of the course content, the results confirm that the knowledge of physics and computing is necessary to solve the challenge, which could indicate that students perceive computing as a tool. The intensive use of mathematics can depend heavily on the challenge itself, and in some cases, it is an area of opportunity. One of the characteristics of CBL is that the contents of all the modules are necessary to solve the challenge, which is observed in this study's results. Another characteristic of CBL is that the challenge is as close to real-life scenarios as possible and close to the student’s interests. The results of this study confirm that the students were interested in the challenge solution, but this could also be improved in subsequent courses.

A characteristic of CBL is that the challenge is close to the work field. In this case, the challenge was evaluated with a 3.88 closeness to the work field. This could be explained because students are in their first semester, so the applications of the challenge still need to be closer to the real-life applications in the work field. However, it is expected that, as students progress in their studies, they will be able to relate the challenges with the work field better. Even with this behavior, around 70% of the students agreed that the challenge allowed them to know the work field better, which is promising in an introductory course. After solving the challenge, the relevance and relationship between math, physics, and computing were mainly perceived as valuable. This is one of the main objectives of the course design, to let students perceive the interdisciplinary aspect of practice in STEM education. By designing interdisciplinary courses, engineering students must understand the relevance of physics, math, and computing when solving engineering problems.

Students perceived the challenge as the highest difficulty and excessive time demand. This could be related to the student's perception of the challenge as less gratifying than motivating or interesting. Besides the challenge, the perceived difficulty and time demand were close to the arithmetic mean, which could mean that the content of the modules is adequate for the students' level—the time dedicated to each of the modules coincided with the student's perception of time demand for the math and computing modules. However, even though the course devoted more time to the physics modules (24 hours) than to the challenge (16 hours), the students perceived they devoted more time to the challenge. This is an area for improvement in the implementation of the CBL model.

Conclusion

In the present study, we presented the design of an interdisciplinary CBL course that integrates knowledge from physics, math, and computing toward solving a challenge for learning Newton's laws of motion. We surveyed students to know their perception of the course in general, the achievement of objectives and value of each module, their experience while solving the challenge, and the perceived difficulty and time demand. The survey's overall results showed high student satisfaction with the Modeling the Movement course. While analyzing and discussing the results, we identified some aspects of the course design that could be improved and others that are expected for the time dedicated to each module, the role each module plays in the challenge solution, and the introductory nature of the course.

We recognize the study's limitations. Student voluntary participation was low, representing 12% of student enrolment in the first semester of engineering. Using a platform like Qualtrics made it possible to apply the survey nationwide. Still, at the same time, students may be less committed to answering the survey than paper and pencil surveys. As part of a broader study, we aim to improve the protocols for data collection by still using the Qualtrics platform and involving instructors to encourage students to participate in the survey. Another limitation is that we can identify constructs like students' motivation, interest, and satisfaction, but we cannot delve into why students perceive the context as they do. A profound nationwide qualitative study would be necessary to understand better the student's experience in the Modeling the Movement course. Moreover, the survey results could be contrasted with actual measures for learning outcomes, such as a pre-post examination.

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