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Curricular Redesign for Integrated STEM Foundations in Engineering Education: The Case of Mathematics and Physics Alignment

Ms. Karina Bradaschia Rocha, Mauá Institute of Technology

PhD student in Mathematics Education at the Pontifical Catholic University of Sao Paulo (PUC-SP), started in the 1st semester of 2023. Master's degree from the postgraduate program in Structural Engineering at the Polytechnic School of the University of São Paulo (POLI-USP), completed in March 2020. Graduated in Civil Engineering at Mauá Institute of Technology (IMT), completed in 2016. From 2017 to March 2020 worked as a coordination assistant and since March 2020 have been working as an assistant professor at IMT in mathematics-related courses. Experience in the field of Civil Engineering, with an emphasis on Structural Engineering. Interested in research areas related to the teaching and learning of Mathematics for Engineering and Structural Engineering courses.

Juliana Martins Philot

I hold a B.A. in Mathematics from Universidade Estadual Paulista Júlio de Mesquita Filho - UNESP (2007), a M.Sc. in Mathematics from Universidade Estadual Paulista Júlio de Mesquita Filho - UNESP (2010) and a Ph.D. in Mathematics Education from Pontifícia Universidade Católica de São Paulo - PUC-SP (2022). I have experience in Mathematics Teaching for Engineering courses since 2009 and currently I am a professor at Instituto Mauá de Tecnologia (IMT). I am interested in research areas related to Teaching and Learning of Mathematics for Engineering courses.

Vinícius da Silva Carvalho

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Introduction

Engineering education has undergone an intense process of reconfiguration on a global scale over the past decades. International reports and academic studies emphasize that contemporary engineers must combine solid scientific foundations with transversal competencies such as critical thinking, complex problem solving, communication, collaboration, and the ability to adapt to uncertain contexts [1], [2], [3]. In Brazil, this debate has intensified in light of the high dropout rates observed in engineering programs, particularly during the first year, which are frequently associated with difficulties in foundational courses such as Calculus and Physics [4], [5]. The transition from secondary education to higher education emerges as a critical point, where conceptual gaps, unfamiliar academic language, and overly lecture-centered pedagogical practices contribute to early student disengagement.

This context brings the very conception of the curriculum back to the center of the debate. On one hand, some approaches advocate for a curriculum strongly oriented toward labor market demands and employability, emphasizing immediately applicable technical skills and alignment with productive expectations [6], [7]. On the other hand, authors such as Sacristán, Pacheco, and Freire argue that the curriculum should prioritize the intellectual development of the learner, fostering autonomy, deep conceptual understanding, and the capacity for critical reading of reality [8], [9], [10]. In engineering education, this tension manifests particularly in the teaching of introductory courses: while the labor market demands engineers capable of modeling, interpreting data, and making informed decisions, traditional curricular structures often fragment Mathematics, Physics, and related areas into isolated compartments, hindering meaning-making and knowledge transfer.

Within this framework, the teaching of Calculus and Physics at the beginning of the program plays a structuring role. Several studies indicate that excessively formal approaches centered on algorithmic exposition tend to amplify the cognitive and symbolic barriers faced by incoming students [11], [12]. Conversely, instructional designs that connect mathematical concepts to physical phenomena and authentic engineering problems tend to promote conceptual understanding and student engagement [13], [14]. Nevertheless, the implementation of integrated curricula continues to face institutional, cultural, and methodological resistance, particularly within academic structures historically organized around disciplinary departments.

It is within this scenario that the central problem addressed in this article is situated: early dropout in engineering programs, strongly associated with difficulties in foundational courses. At the Instituto Mauá de Tecnologia (IMT), the institution examined in this study, historically high failure rates in Differential and Integral Calculus I (hereafter Calculus I) and Physics I, combined with an increasingly heterogeneous student population, had been producing academic trajectories marked by frustration, discontinuity, and early withdrawal. The first year thus became an implicit filter, more closely related to students' resistance to the prevailing academic model than to the effective development of engineering competencies.

In response to this challenge, this article proposes understanding diagnostic assessment not merely as an initial measurement instrument, but as a strategic tool for managing learning processes. Grounded in the work of authors such as [15], [16], and [17], diagnostic assessment is conceived as a formative device capable of revealing learning gaps, guiding pedagogical interventions, and supporting processes of curricular personalization. Unlike assessment models focused on classification, this approach enables continuous monitoring of students' trajectories, adjustment of learning rhythms, reorganization of instructional experiences, and alignment of expectations between instructors and students. In the context of the first year of engineering programs, this perspective is particularly powerful, as it allows the curriculum to respond to the actual profile of each incoming cohort.

Within this framework, this article aims to analyze a set of curricular interventions implemented in the first year of engineering programs at IMT, with a particular focus on the integrated redesign of Calculus I and Physics I, guided by the results of an institutional diagnostic assessment. The study seeks to examine the extent to which disciplinary alignment, the reorganization of pedagogical practices, and the systematic use of institutional data are reflected in indicators of academic performance and student persistence, including course averages, approval rates, and institutional first-year attrition rates (considering first-time entrants). This research is limited to the analysis of a single Brazilian institution and a specific time frame. It does not intend to propose a universal model, but rather to highlight principles, strategies, and empirical evidence that may inform similar curricular reform initiatives in engineering education.

Methodological Approach

This study adopts a mixed-methods approach, guided by the logic of triangulation between quantitative and qualitative data, as proposed by [18] in their most recent formulation of mixed methods research. The choice of this methodology stems from the nature of the research problem: understanding the effects of curricular interventions in the first year of engineering programs requires, simultaneously, capturing objective evidence of academic performance and student retention, as well as interpreting pedagogical processes, faculty perceptions, and institutional dynamics that cannot be fully accounted for through numerical indicators alone.

Within the adopted perspective, methodology is not limited to the selection of research techniques; rather, it expresses the epistemological logic that guides knowledge production in this study. The analysis is grounded in the understanding that complex educational phenomena, such as dropout, engagement, and learning, are multifaceted and require multiple analytical lenses. Quantitative data make it possible to identify patterns, trends, and measurable variations in student performance and persistence, while qualitative data enable the interpretation of meanings attributed to curricular changes, the pedagogical rationales involved, and the institutional processes that support the interventions.

Triangulation, in this context, is not merely confirmatory. Different data sets are placed in dialogue through a complementary and interpretive process, seeking convergences, tensions, and gaps between statistical results and qualitative evidence. This strategy strengthens the internal validity of the study, expands analytical depth, and allows the findings to be understood both in terms of measurable impact and pedagogical and institutional significance.

The methodological design approximates a convergent mixed methods model, in which quantitative and qualitative evidence are collected in parallel, analyzed separately, and integrated during the interpretive phase. In this study, statistical results were examined in dialogue with faculty reports and institutional documents, enabling the articulation of measurable indicators of academic performance with contextual evidence regarding pedagogical practices and curricular organization. This integration sought to understand not only whether variations occurred in the results, but also how such variations may be interpreted considering the interventions implemented. Table 1 summarizes the stages of the methodological pathway, indicating the predominant approaches, the methods employed, and the analytical purposes of each phase of the study.

Table 1. Summary of the Study's Methodological Design

Study Stage	What Was Conducted	Predominant Approach	Method Employed	Analytical Purpose
Research Design Planning	Definition of the methodological model with parallel collection of quantitative and qualitative evidence	Mixed Methods	Convergent Mixed Methods Design	To structure the study in order to generate complementary evidence regarding the investigated phenomenon
Collection of Academic Performance Data	Compilation of measurable educational outcome indicators	Quantitative	Statistical data collection (educational records)	To identify patterns, variations, and performance trends
Collection of Pedagogical and Institutional Context Data	Compilation of faculty reports and analysis of institutional documents	Qualitative	Document analysis and analysis of professional reflective reports	To understand pedagogical practices, curricular organization, and implementation context
Quantitative Data Analysis	Processing and statistical analysis of performance indicators	Quantitative	Statistical analysis	To identify changes, variations, and possible effects of the interventions
Qualitative Data Analysis	Interpretation of faculty reports and institutional documents	Qualitative	Interpretive content analysis	To understand meanings, processes, and pedagogical dynamics
Interpretive Integration of Findings	Comparison and articulation of quantitative and qualitative findings	Mixed Methods (Integration)	Interpretive triangulation (convergent integration)	To explain quantitative results in light of contextual and pedagogical evidence
Final Interpretation and Applied Knowledge Production	Explanatory synthesis of observed variations and their relationship to curricular interventions	Mixed Methods (Synthesis)	Explanatory integration oriented toward decision-making	To produce situated knowledge that supports educational decision-making

2.1 Methodological Pathway

The methodological pathway operationalizes the adopted approach through an articulated set of stages, techniques, and research instruments. Initially, quantitative data related to students' academic performance in Calculus I and Physics I were collected for the academic years of 2024 and 2025. These data included:

1. Average scores on regular assessments throughout the academic year;
2. Average scores calculated after considering substitution exams;
3. Indicators associated with student persistence (final course average and approval/failure rates) in the disciplines;
4. Institutional first-year attrition rates, considering first-time entrants (excluding students retaking courses and repeaters).

The quantitative analysis focused on comparing the two academic years, identifying variations in average scores, performance patterns in the initial assessments, and changes in approval rates, in order to obtain objective evidence of the effects of the curricular interventions implemented in 2025. Additionally, attrition data refer exclusively to first-time entrants and are therefore not directly comparable to course-level indicators, which include students retaking courses and repeaters. In parallel, qualitative data were produced and systematized based on:

1. Institutional records documenting the disciplinary redesign process;
2. Pedagogical documents (course syllabi, instructional materials, and proposals related to the Mathematics Learning Pathway);
3. Faculty reports from instructors involved in the redesign;
4. Observations of the implementation process conducted by the academic coordination team.

Faculty accounts related to the disciplines under analysis were systematized into reflective records produced by the responsible instructors and the academic coordination team throughout the implementation process. These records, together with institutional documents and revised course syllabi, were subjected to a categorical analysis inspired by content analysis [19], aiming to identify evidence related to four main axes: (i) reorganization of instructional time, (ii) formative use of diagnostic assessment, (iii) student engagement and persistence indicators throughout the academic year, and (iv) conceptual alignment among first-year disciplines. The categories were constructed based on thematic recurrence observed in the records and were subsequently integrated with the quantitative results during an interpretive phase.

This integration occurred through the construction of common analytical axes, such as initial performance, persistence, engagement, and curricular coherence, within which statistical data were placed in dialogue with qualitative evidence. The objective was not merely to verify whether the data "confirmed" one another, but to understand how the observed effects articulate with the pedagogical and institutional processes described.
This methodological pathway allowed the study to move beyond an impact analysis restricted to numerical indicators, offering a broader understanding of the investigated phenomenon: how the integrated redesign of Calculus I and Physics I, guided by diagnostic assessment, reconfigures

the academic experience in the first year and creates more favorable conditions for learning and academic progression.

Thus, while the methodology defines the overall rationale and logic guiding knowledge production in this study, the methodological pathway explicates the concrete process of that production, describing the stages, instruments, and analytical choices that made it possible to rigorously and contextually investigate the relationship between curriculum, assessment, and indicators associated with student persistence in engineering education.

2.2 Institutional and Curricular Context

IMT is a private nonprofit institution founded in 1961, with a well-established tradition in engineering education in Brazil. Located primarily on the São Caetano do Sul campus, IMT comprises a University Center and a Research Center, bringing together academic, laboratory, and technological infrastructure dedicated to teaching, research, and outreach activities. Its engineering programs, including Civil, Mechanical, Electrical, Production, and Chemical Engineering, have historically emphasized the articulation between scientific foundations and professional application, establishing the institution as a national reference in the field.

Despite this prestige, until 2024 the foundational cycle of IMT's engineering programs maintained a strongly traditional curricular organization. Core courses, such as Calculus I, were offered in large sections, with two weekly classes predominantly centered on lectures. Support strategies, including remedial classes and office hours, operated as complementary measures, generally in a reactive manner and disconnected from the actual pace of regular instruction.

Within this structure, a significant misalignment among introductory courses was observed. In particular, Calculus I, Physics I, and Vectors, Curves, and Surfaces adopted poorly articulated languages, notations, and conceptual sequences. It was common, for example, for differentiation and integration techniques to be required in Physics before the formal construction of these concepts in Calculus, leading students to apply mathematical procedures in an essentially algorithmic manner, without adequate conceptual support. This scenario contributed to cognitive conflicts among students who were still in the process of transitioning to the academic language of higher education.

As a result, historical failure rates in Calculus I ranged between 35% and 40%, making the course a critical bottleneck in the first year of the program. Many students began to experience significant difficulties by the middle of the semester, which frequently translated into progressive disengagement and eventual dropout.

This situation became even more pronounced considering the increasingly heterogeneous profile of incoming students, marked by gaps in fundamental mathematical knowledge, partly associated with recent reforms in Brazilian secondary education. At the same time, institutional pressure intensified to reduce first-year dropout rates and to establish a closer, more formative relationship with students.

This context highlights the need for interventions that go beyond isolated adjustments and promote a more integrated reorganization of the foundational cycle, articulating courses, pedagogical practices, and assessment strategies. It is within this scenario that the set of actions analyzed in this article is situated, conceived as the initial phase of a broader curricular reform process within IMT's engineering programs.

2.3 Initial Phase of a Broader Curricular Reform

The transformations analyzed in this study correspond to the initial stage of a broader curricular reform process within the engineering programs at IMT. The curriculum in effect at the time, which had been in operation for approximately a decade, was designed within an educational, social, and technological context substantially different from the current one. Changes in the profile of incoming students, intensified by recent reforms in Brazilian secondary education, combined with the rapid expansion of digital technologies, particularly artificial intelligence and the growing role of computation in engineering education, highlighted the need for a structural revision of the institution's pedagogical project.

The implementation of the new curriculum is scheduled to begin progressively in 2026. However, throughout 2025, the institution chose to anticipate a set of targeted pedagogical interventions focused on the first year, with two immediate objectives: reducing student dropout and enhancing the academic experience of incoming cohorts. These actions do not yet constitute the full implementation of the new curriculum; rather, they represent a strategic transitional movement. They anticipate changes in course organization, pedagogical practices, and interdisciplinary articulation, while simultaneously creating the institutional, cultural, and methodological conditions necessary for the future adoption of a more integrated, contemporary, and learning-oriented curriculum.

Within this perspective, the first year came to be understood as a priority space for pedagogical experimentation, in which structural adjustments could produce direct effects on student engagement, persistence, and the construction of academic belonging. The interventions described in the following sections should therefore be interpreted as part of an ongoing process, situated between the traditional curriculum and the new model currently under development.

2.4 Redesign of First-Year Calculus

Within the scope of these initial interventions, Calculus I underwent a significant structural and pedagogical reorganization when compared to how the course had been delivered in previous years at IMT. The former model, centered on two weekly lecture-based classes, was replaced by a structure consisting of one theory class and one exercise-based class per week. While the theory classes brought together approximately 60 students, the problem-solving classes were organized into smaller groups of around 30 students, fostering closer interaction between instructors and students.

The exercise-based classes assumed a central role in the learning process. During these sessions, students were encouraged to actively solve problems through hands-on engagement, while the instructor acted as a mediator, working individually or with small groups, addressing specific questions, and guiding students' reasoning. Board-based exposition and formal conceptual presentation were used only when strictly necessary. The proposed exercises emphasized applied engineering contexts, seeking to connect mathematical content to real situations from professional practice. In many cases, it was necessary to simplify models to make them compatible with the level of preparation of incoming students, without severing their connection to authentic engineering problems.

As a complement to this reorganization, a Mathematics Learning Pathway was created as a formative space integrated into the institutional schedule, although it was not configured as a formal course within the curriculum. During the first academic term, the Learning Pathway focused on revisiting foundational secondary-school mathematics concepts considered essential for following Calculus I. From the second term onward, it operated in parallel with the course, reinforcing and deepening the content addressed in regular classes.

With a focus on engaging first-year students, the course adopted a dynamic of frequent activities throughout the exercise-based sessions. After guided practice, the final minutes of each class were devoted to short application tasks, often with an evaluative component. These activities were designed to increase engagement, sustain attention during class, and promote conceptual consolidation. Moreover, they explicitly addressed learning gaps identified through the institutional diagnostic assessment, enabling more targeted interventions related to difficulties stemming from students' prior educational backgrounds. Within the Mathematics Learning Pathway, this engagement was further reinforced through short weekly assessments, whose scores were incorporated into the Calculus I course grade as part of the coursework component, establishing a direct link between participation and academic performance.

The Learning Pathway was conceived as a direct response to the results of the institutional diagnostic assessment administered during the first week of classes, which covered content in Mathematics, Physics, and Chemistry. This assessment made it possible to identify specific gaps in students' prior knowledge and to guide more precise pedagogical interventions.

In addition to conceptually preparing students for Physics, Calculus I intentionally incorporated situations and concepts already addressed in Physics I as contexts for mathematical application. Physical quantities, functional relationships, and problems discussed in Physics I were revisited in Calculus I classes as examples and exercises, enabling students to recognize Mathematics as a tool for modeling and understanding physical phenomena. This strategy strengthened integration between the disciplines, highlighted conceptual connections, and supported knowledge transfer within the foundational cycle.

2.5 Alignment with First-Year Physics

Analogous changes were implemented in Physics I with the aim of strengthening curricular integration and bringing the teaching and learning process closer to the needs of incoming students. The previous model, consisting of one weekly lecture and one laboratory session, was replaced by a structure composed of one exercise-based class and one laboratory session, both organized in reduced-size groups, limited to approximately 25 students in laboratory sections and 30 students in exercise-based classes.

The pedagogical approach was reorganized to preserve conceptual rigor while redistributing in-class time. The theoretical presentation occupied approximately 40 to 60 minutes, depending on the topic, with the remaining time dedicated to problem solving and individualized support. As in Calculus, the frequency of in-class activities increased: following the presentation of concepts and guided problem solving, the final minutes of each class were devoted to a short application activity with an evaluative component.

These activities were designed to enhance student engagement, sustain attention, and promote consolidation of the concepts addressed. The exercise-based classes also explicitly considered learning gaps identified through the institutional diagnostic assessment, addressing not only the planned course content but also difficulties stemming from students' prior educational backgrounds.

Taken together, these actions constituted a substantive reformulation of the first-year academic experience, shifting the focus from a predominantly lecture-based model toward an approach centered on active learning, curricular coherence, and close student monitoring. Although implemented within an initial and transitional phase of the broader curricular reform, these interventions established important foundations for the new engineering curriculum scheduled to be implemented beginning in 2026, while simultaneously addressing the immediate challenges of student dropout and engagement in the foundational cycle.

2.6 Assessment Structure and Final Grade Calculation

The institution analyzed adopts an annual academic system divided into four academic terms (bimesters). In both disciplines investigated (Physics I and Calculus I), student performance is composed of written examinations and coursework completed throughout the academic year. Over the course of the year, four regular examinations (P1, P2, P3, and P4) are administered. According to institutional academic regulations, the exams carry different weights: P1 and P2 have weight 2, whereas P3 and P4 have weight 3. The exam average (MP) is calculated individually for each student, as shown in Equation 1:

$$\mathrm{MP} = (2\mathrm{P1} + 2\mathrm{P2} + 3\mathrm{P3} + 3\mathrm{P4}) / 10 \tag{1}$$

At the end of each semester, a substitution exam is administered. The score obtained on this exam may replace the two regular exams of the corresponding semester if it is higher than the original scores. Therefore, the values of P1 and P2 (first semester), as well as P3 and P4 (second semester), correspond to the final exam scores after the substitution process. This mechanism is intended to provide an opportunity for academic recovery and consolidation of learning, without altering the overall weighting structure of the assessment system.

The composition of the final course average (MF) differs between the disciplines:

- **Physics I:** 60% of the exam average (MP) and 40% of the coursework average (T1–T4), corresponding to activities distributed across the four academic terms.
- **Calculus I:** 70% of the exam average (MP) and 30% of the coursework average. In this discipline, coursework grades are consolidated into T1 (first semester) and T2 (second semester).

The institutional approval criterion establishes a minimum final average (MF) of 6.0 for course completion. This clarification is essential for the appropriate interpretation of the results presented in the following section.

Results and Discussion: Academic Performance, Persistence, and Curricular Impact

The institution analyzed in this study is a private higher education institution in Brazil that operates under an annual academic system, unlike the semester-based structures common in many engineering programs internationally. The assessment framework described in Section 2.6 underpins the interpretation of the results presented below.

Based on this structure, this section presents a quantitative analysis of student academic performance in Physics I and Calculus I, comparing the academic years 2024 and 2025. The analysis focuses on three levels: (i) performance in regular assessments throughout the year, (ii) consolidated performance considering substitution exams, and (iii) final course averages and approval rates. The objective is to investigate whether the curricular and pedagogical changes implemented in 2025 were reflected in measurable improvements in learning outcomes and indicators associated with academic persistence. In Physics I, the sample included N = 325 (2024) and N = 441 (2025); in Calculus I, N = 399 (2024) and N = 465 (2025).

To assess whether the differences observed between 2024 and 2025 were statistically significant, independent-samples t-tests were conducted comparing exam averages (MP) and final course averages (MF) across the two years. For approval rates, a chi-square test of independence was applied, considering the institutional approval criterion (MF $\geq$ 6.0). The level of significance adopted was $\alpha = 0.05$. All analyses compared the two academic years as independent groups.

Initially, the averages of regular examinations (P1 to P4) and coursework grades (T1 to T4) were analyzed without considering substitution exams, in order to capture student performance throughout the academic year prior to the application of compensatory mechanisms. This analysis is particularly relevant for understanding sustained student engagement and content follow-up across the year.

The data presented in Table 2 indicate a substantial improvement in the averages of the initial assessments (P1 and P2) in both disciplines when comparing 2024 and 2025. In Physics I, the average for P1 increased from 4.63 in 2024 to 6.62 in 2025 (an increase of approximately 2.0 points) while the average for P2 rose from 4.15 to 5.10. Similarly, in Calculus I, the average for P1 increased from 5.11 to 6.95, and P2 from 4.92 to 6.02. It is important to note that the averages presented in Table 2 correspond to direct means of the original exam scores and therefore do not reflect the substitution process used in the calculation of individual exam averages (MP).

Table 2. Average scores excluding substitution exams

Discipline	Year	P1	P2	P3	P4	T1	T2	T3	T4
Physics I	2024	4.63	4.15	3.93	6.19	7.00	7.44	7.13	7.31
	2025	6.62	5.10	4.98	4.81	7.80	8.26	7.61	7.56
Calculus I	2024	5.11	4.92	3.24	5.25	6.30	4.94	–	–
	2025	6.95	6.02	4.80	3.99	7.55	7.31	–	–

It is important to emphasize that, from 2024 to 2025, the examination system remained unchanged in both disciplines. Therefore, the observed gains cannot be attributed to modifications in assessment format but should instead be interpreted in light of the pedagogical interventions implemented.

The analysis of consolidated exam averages revealed distinct patterns between the disciplines. In this context, the reported values correspond to the mean of the individual exam averages (MP) computed for each student after the application of substitution rules, as defined in Section 2.6. In Physics I, a statistically significant increase in exam averages was observed between 2024 (MP = 5.13) and 2025 (MP = 5.51), $p = 0.013$. In Calculus I, however, no statistically significant difference in exam averages was identified between the two years (2024: MP = 5.69; 2025: MP = 5.59; $p = 0.524$). These results indicate that the impact on regular assessment performance was more consistent in Physics I, although both disciplines show descriptive improvements in the first assessments of the year.

Subsequently, averages were analyzed considering the application of substitution exams, as presented in Table 3. In this case, the reported exam scores (P1–P4) already reflect the substitution process, although they are still presented as descriptive means of each assessment, rather than reconstructed from individual MP values.

Table 3. Average scores including substitution exams

Discipline	Year	P1	P2	P3	P4	T1	T2	T3	T4
Physics I	2024	5.21	4.97	4.77	6.40	7.00	7.44	7.13	7.31
	2025	6.67	5.36	5.47	5.30	7.80	8.26	7.61	7.56
Calculus I	2024	6.20	5.97	5.34	6.40	6.30	4.94	–	–
	2025	6.97	6.18	5.53	4.93	7.55	7.31	–	–

When examining final course averages (MF), which incorporate both exam averages and coursework according to institutional weightings, a statistically significant increase was observed in both disciplines. In Physics I, the final average increased from 5.87 in 2024 to 6.33 in 2025 ($p < 0.001$). In Calculus I, the final average increased from 5.63 to 6.08 ($p = 0.002$).

This result is particularly relevant in Calculus I, as it indicates that although exam averages alone did not show statistically significant variation, overall performance, incorporating coursework distributed throughout the year, was positively affected by the changes implemented in 2025.

Additionally, coursework averages (T1 and T2) were higher in 2025 in both disciplines. In 2024, the disciplines were primarily assessed through a single larger assignment at the end of each term. In 2025, they adopted a greater number of shorter activities distributed throughout the classes. This reorganization favored more continuous monitoring of learning, expanded opportunities for feedback, and contributed to a more formative assessment process.

The analysis of approval rates also revealed distinct patterns between the disciplines. In Physics I, the approval rate increased from 64.6% in 2024 to 76.2% in 2025, a statistically significant difference ($p < 0.001$). In Calculus I, the approval rate increased from 65.4% to 68.6%; however, this difference did not reach statistical significance ($p = 0.356$). These results indicate a more robust impact of the interventions in Physics I, while in Calculus I the effects were more moderate, primarily concentrated in the final course average.

Overall, the results suggest that the redesign of pedagogical and assessment practices implemented in 2025 produced measurable effects on academic indicators, particularly in Physics I, where significant increases were observed in exam averages, final course averages, and approval rates. In Calculus I, although exam averages remained statistically stable, the significant increase in final averages indicates that continuous monitoring and the reorganization of coursework contributed to improved aggregate performance.

Beyond course-level performance indicators, institutional data on first-year attrition were analyzed, considering exclusively first-time entrants (excluding students retaking courses and repeaters). In 2024, there were 460 first-time entrants, of whom 184 withdrew, corresponding to an attrition rate of 40.0%. In 2025, there were 504 first-time entrants, with 113 withdrawals, resulting in an attrition rate of 22.4%. A chi-square test of independence indicated that this reduction was statistically significant ($\chi^2 = 34.05$; $p < 0.001$).

As a descriptive benchmark comparison, applying the 2024 attrition rate (40.0%) to the number of first-time entrants in 2025 ($N = 504$) would yield an expected number of approximately 202 withdrawals. The observed number in 2025 (113 withdrawals) is substantially lower than this reference estimate. Although this comparison does not establish a direct causal relationship, it highlights the magnitude of the reduction observed following the interventions implemented in 2025. This estimate relies solely on the previous year's attrition rate and does not control differences in student profile, institutional policies, or external factors; therefore, it should be interpreted as an illustrative comparison of magnitude rather than a causal counterfactual.

Beyond numerical indicators, qualitative analysis of faculty records and institutional documents provides relevant interpretive elements for understanding the observed results. The qualitative analysis was based on reflective records produced by the faculty responsible for the disciplines, institutional documents, and observations from the academic coordination team during the implementation of curricular changes in 2025. The systematization of these materials enabled the identification of three central axes of transformation: (i) reorganization of instructional time and classroom dynamics, (ii) formative use of diagnostic assessment as a pedagogical guidance tool, and (iii) conceptual alignment among first-year disciplines.

In Physics I, the primary structural change consisted of replacing one predominantly theoretical weekly session with an exercise-based session characterized by more active engagement. Although conceptual rigor was maintained, lecture time was reduced, reserving significant time for guided problem-solving and distributed activities throughout the academic terms. In Calculus I, a similar shift was implemented: two weekly theoretical classes were reorganized into one theory session and one exercise session, with reduced class sizes in the latter. The introduction of more frequent activities (though individually shorter) favored continuous monitoring and more immediate feedback.

According to faculty reports, this reorganization contributed to increased classroom attendance throughout the academic year, reducing the classroom emptying observed in previous years after the first assessments. Although such evidence is qualitative in nature and not derived from standardized student perception instruments, it indicates a meaningful shift in engagement dynamics.

The diagnostic assessment applied at the beginning of the year was designed based on historically recurring difficulties identified by faculty. Although it informed the design of the Mathematics Learning Pathway, it was not possible at that time to implement fully individualized monitoring strategies. After the first examination (P1), students performing significantly below the mean were invited to participate in guidance meetings and targeted support sessions. While initial adherence to the meetings was satisfactory, participation in subsequent support classes was limited. This finding suggests that simply offering additional support does not guarantee engagement, underscoring the complexity of factors involved in academic persistence.

Another central axis identified was the intentional alignment among Calculus I, Vectors, Curves and Surfaces, and Physics I. In 2025, content sequencing was reorganized so that foundational derivative concepts were consolidated in Calculus I before their formal application in Physics I in the study of motion. Similarly, vector-related content (including coordinate operations, dot product, and cross product) was developed beforehand in Vectors, Curves and Surfaces.

Thus, when Physics I introduced the study of motion in the third academic term, students already possessed the necessary mathematical and vector tools for modeling in one and two dimensions. Faculty reports and implementation observations suggest that this reorganization contributed to greater perceived conceptual coherence in the classroom, particularly in the treatment of derivatives as rates of change and in the use of vector notation for position and velocity. It should be noted, however, that such evidence derives from reflective records rather than standardized student perception instruments.

These qualitative findings provide interpretive elements for the quantitative results, particularly in Physics I, where statistically significant increases were observed in exam averages, final course averages, and approval rates. The reorganization of instructional time, the expansion of formative activities, and the conceptual alignment among disciplines constitute plausible mechanisms for explaining these variations. In Calculus I, although exam averages remained statistically stable, the significant increase in final averages may be associated with the higher frequency of distributed activities throughout the year, reinforcing the importance of continuous monitoring in consolidating learning.

This articulation between quantitative and qualitative evidence supports the interpretation that the changes implemented in 2025 were not limited to administrative adjustments but rather involved a pedagogical reconfiguration with measurable effects in the first year.

Conclusion

This article analyzed a set of curricular interventions implemented in the first year of the Engineering programs at the Instituto Mauá de Tecnologia, focusing on the integrated redesign of Calculus I and Physics I, guided by the results of an institutional diagnostic assessment. The changes implemented included the reorganization of instructional time, the expansion of formative activities distributed throughout the academic year, and conceptual alignment among foundational disciplines, aiming to address a recurring and widely documented problem in the literature: the high failure rates associated with foundational courses, particularly at the beginning of engineering students' academic trajectories.

The quantitative results revealed differentiated impacts across the two disciplines. In Physics I, statistically significant increases were observed in exam averages, final course averages, and approval rates, suggesting a consistent effect of the interventions implemented. In Calculus I, although exam averages did not show statistically significant variation, a significant increase was observed in the final course average, indicating that the reorganization of assessment activities and the continuous monitoring of learning contributed to improved overall performance.

This distinction is relevant from an interpretive standpoint. In Physics I, the results suggest an impact both on performance throughout the assessments and on the final course outcome. In Calculus I, the effects appear to be concentrated in the consolidation of learning at the end of the course, possibly associated with the increased number of activities distributed throughout the year and the formative reinforcement provided by the Mathematics Learning Pathway.

Beyond course-level indicators, institutional analysis of attrition among first-time entrants revealed a substantial reduction during the period analyzed. The attrition rate decreased from 40.0% in 2024 to 22.4% in 2025, a statistically significant difference, indicating meaningful improvement in an institutional indicator of first-year persistence. Although these data refer exclusively to first-time entrants (excluding repeaters and students retaking courses), the magnitude of the observed reduction reinforces the hypothesis that the curricular interventions implemented in 2025 were associated with structural changes in the initial academic experience.

The qualitative analysis provides explanatory elements for these findings. The partial replacement of a predominantly lecture-based model with structured, guided problem-solving sessions expanded opportunities for supervised practice and immediate feedback. Furthermore, the intentional alignment among Calculus I, Vectors, Curves and Surfaces, and Physics I reduced the conceptual fragmentation historically observed in the foundational cycle, allowing concepts such as derivatives and integrals to be mobilized in Physics I only after their formal consolidation in Mathematics. This sequencing may have contributed to greater cognitive coherence and to students' construction of meaning.

Nevertheless, the results should be interpreted with caution, considering the institutional and context-specific nature of the study, as well as the absence of formal student perception instruments that would allow for systematic evaluation of the student experience. The attrition analysis, although statistically robust, does not establish a direct causal relationship, but rather indicates a consistent association between the curricular redesign and indicators of persistence.

From a theoretical perspective, the findings reinforce the importance of understanding the first year of Engineering not merely as a stage for transmitting foundational content, but as a strategic space for building academic bonds, fostering intellectual autonomy, and integrating areas of knowledge. Interventions that articulate pedagogical reorganization, formative assessment, and curricular alignment appear to constitute promising pathways for addressing longstanding challenges related to performance and retention in foundational courses.

As future developments, longitudinal monitoring of subsequent cohorts of first-time entrants is recommended to verify the sustainability of the observed effects, as well as the incorporation of formal qualitative data collection instruments directed at students. Such investigations may provide deeper insight into the mechanisms through which curricular alignment and the reorganization of pedagogical practices influence academic trajectories throughout the program.

In summary, the results suggest that structural reforms in the first year, when grounded in institutional diagnosis, interdisciplinary integration, and continuous monitoring of learning, can produce measurable short-term effects. This study thus contributes to the contemporary debate on curricular innovation in engineering education, offering empirical evidence and plausible pedagogical mechanisms that may inform similar reform experiences in other institutional contexts.

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