A Continous Evaluation System for a Challenge-Based Structural Engineering Courses

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A Continous Evaluation System for a Challenge-based Educational Model for Structural Engineering Courses

Abstract

This article introduces an innovative educational methodology designed to enhance learning outcomes in structural engineering education by implementing immediate and adaptive evaluations. Emphasizing the significance of real-time feedback and homogenization of learning among students, this approach is tailored to generate the assessment indicator since the course's early days, allowing students to engage with the subject matter. The study systematically examines the impact of this pedagogic strategy on student performance and motivation across various engineering courses, taking into account three essential dimensions: i) course period, ii) course modality in remote and in-person settings, and iii) Study curricula: Objective-based vs. Competence- Problem-Based Learning (PBL). By integrating dynamic assessment tools within the curriculum, the research underscores the potential of adaptive learning technologies to transform traditional educational paradigms, promoting a more interactive and student-centered learning environment. The findings highlight the effectiveness of immediate, contextual evaluations in improving student engagement and perception and influence of the course's period, suggesting that such methods could serve as a blueprint for future educational innovations, particularly in disciplines requiring a high level of problem-solving and critical thinking skills as in structural engineering.

Introduction

In the fall of 2019, our university *Tecnológico de Monterrey*, rolled out its new educational model called Tec21 across all programs, including engineering. In this model, the semester periods were divided into three periods of 5 weeks each, where subjects from the previous curriculum, which lasted 18 weeks, were condensed into a 5-week teaching period. This approach was based on entirely focusing students on a thematic area (Fig.1).

In the Tec21 curriculum plans [1-5], each thematic block is structured with several modules on related themes and a challenge (linked project), which must be addressed by developing skills derived from the deployment of the modules. All challenges are linked to real-world environmental problems through Educational Partners (companies, government institutions, non-governmental organizations, etc.).

In this process, ensuring students acquire competencies during the module deployment is crucial for solving the challenge, with one of the main challenges being the assimilation of thematic content within a shortened period. Some techniques of virtualization of projects, such as Building Information Models (BIM), have also been successfully used in other implementations of the educational model [6-8].

Daily sessions last an average of 4 hours, with 70% of the time dedicated to teaching module content, while the remaining percentage is dedicated to developing the challenge solution with the support of teachers and partners. During the content teaching time, various strategies are used to maintain the attention of the groups, including continuous assessment through adaptive parametric quizzes.

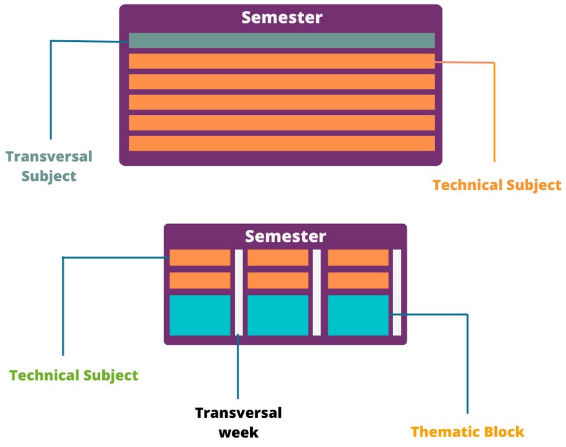

Figure 1. A model for semesters in our educational model

From the student's perspective, the Tec21 model means that students must quickly adapt to the context of the subject and instructor, and the instructor needs to generate products (evidence) for evaluation from the first days to build the cognitive scaffolding from which content knowledge can be escalated to practical application (know-how) while also building attitudinal aspects must be constructed. As students develop skills, it is necessary to guide them in forming abilities (the art of doing things) consistently and daily within the blocks, in addition to maintaining their attention and engagement. In the previous text, it was written that homogenization is relevant to achieving the same level of perception in the learning process and progress in the cohort of students. While homogenization cannot be assessed with grades, the metric used in this paper for student perception does.

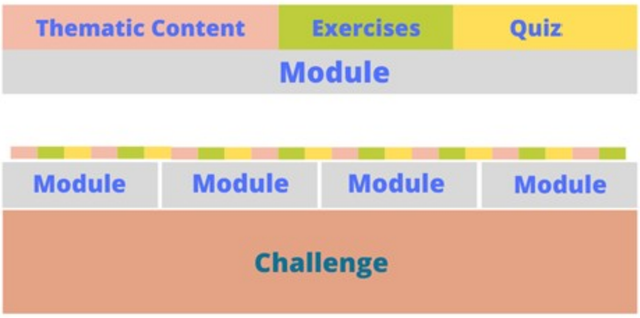

Figure 2 Strategy of a block course

Innovation in the teaching strategy

To assess the innovation and narrow down the pertinent information (paper, books, reports, book chapters), this research conducted a cluster analysis, finding the following ten semantic keyword groups that are interconnected:

1) Adaptative Learning
2) Immediate Evaluation
3) Structural Engineering Education
4) Remote Learning Technologies
5) In-person Teaching Strategies
6) Blended Learning Approaches
7) Educational Assessment Methods
8) Digital Tools and Applications
9) Student Engagement and Motivation
10) Challenges and Solutions in Eng. Education

Even if Project-based Learning has been widely used in several disciplines [9-21], the approach used for this course considered novel points described in the following sections, taking some elements from Project-based learning.

The previous ten enumerated points are a semantic field containing related keywords. By forming this thematic group of keywords, it is possible to carry out a clustering analysis, helping to establish a point of innovation by applying the teaching strategy. The following keywords were used:

Table 1. Groups of semantic keywords

G1. ADAPTATIVE LEARNING • Personalized learning • Adaptative education systems • Learning Analytics • Customized learning paths • Adaptative feedback	G2. IMMEDIATE EVALUATION • Real-time feedback • Instant assessment • Formative assessment • Continuous assessment • Automated grading	G3. STRUCTURAL ENGINEERING EDUCATION • Civil engineering pedagogy • Structural analysis teaching • Engineering Mechanics • Construction materials education • Structural design courses
G4. REMOTE LEARNING TECHNOLOGIES • E-learning platforms • Virtual classrooms • Online laboratories • Distance learning tools. • Web-based education	G5. IN-PERSON TEACHING STRATEGIES • Active learning • Collaborative learning • Hands-on training • Face-to-face interaction • Classroom engagement	G6. BLENDED LEARNING APPROACHES • Hybrid courses • Flipped classroom • Online and offline integration • Synchronous and asynchronous learning • Blended learning models
G7. EDUCATIONAL ASSESSMENT METHODS • Competency-based assessment • Peer assessment • Self-assessment • Rubrics • Formative and summative evaluation	G8. DIGITAL TOOLS AND APPLICATIONS • Educational software • Simulation tools • Learning management systems • Education apps • Online quizzes and exams	G9. STUDENTS ENGAGEMENT AND MOTIVATION • Student-centered learning • Engagement strategies • Motivational techniques • Interactive learning environments • Gamification in Education
G10. CHALLENGES AND SOLUTIONS IN ENGINEERING EDUCATION • Remote learning challenges • In-person learning barriers • Education Equity • Remote learning challenges • In-person learning barriers		

The semantic group of keywords in Table 1 was combined, as Table 2 mentions. The combination of these semantic groups was used to create search strings for each combination, and by using a scientific search engine (web of science), different publications at international and transdisciplinary levels were found. They used the complete reference information (title, abstract, and keywords) of the population of papers (in this case, 252 publications among those were books, chapters, scientific indexes papers, conference papers, and reports); the clustering analysis was performed for the content of words that each publication has.

Table 2. Combination of semantic groups of keywords

Num. of combination	Number of groups	Combined groups	Publication
1	2	1 2	252
2	3	1 2 4	4
3	3	1 2 5	15
4	3	1 2 6	2
5	3	1 2 7	20
6	3	1 2 8	16
7	3	1 2 9	3
8	3	1 2 10	0
9	3	1 2 4 3	4
10	4	1 2 5 3	0
11	4	1 2 6 3	0
12	4	1 2 7 3	0
13	4	1 2 8 3	0
14	4	1 2 9 3	0
15	4	1 2 10 3	0

Groups 1 and 2 are general groups due to the research topic of this work. Table 2 shows that engineering education-related keyword groups (3 and 10) reduce/eliminate the publication when combined with other groups, so one could hypothesize that engineering education research is a research gap. The combination of groups 1 and 2 has other related publications, and this population of references was taken to carry out the clustering analysis to capture a picture of the publications related to this research topic. From the clustering analysis of the reference content, figures 3 (clusters image) and 4 (overlay image) were obtained using Vosviewer software.

In the clustering analysis image (see figure 3), it is recognized that 4 out of the 10 clusters of different colors are dispersed in the periphery: light blue cluster (right) where keywords are related to medical education, pink cluster (top right) related to inquiry-based learning, assessment of literacy that can be furnished with gamification, brown cluster (top left) where engineering education is in relation with education policy (traditional cluster) and yellow cluster (bottom left) related to technology in learning. It is essential to see that the light blue (medical education-related cluster) is only related to the center with essential keywords (e.g., sensor, training) and, not surprisingly, on the opposite side of the brown cluster where engineering education is located. However, the light blue cluster is closer to real-time feedback and continuous assessment keywords in the publication's constellation. While technologies in learning and assessment flank engineering education (brown cluster), keywords are not associated with this paper's topics in the constellation of publications. The blue cluster (center of the graph in Figure 3) is related to student perception and engagement terms, keywords relevant to learning.

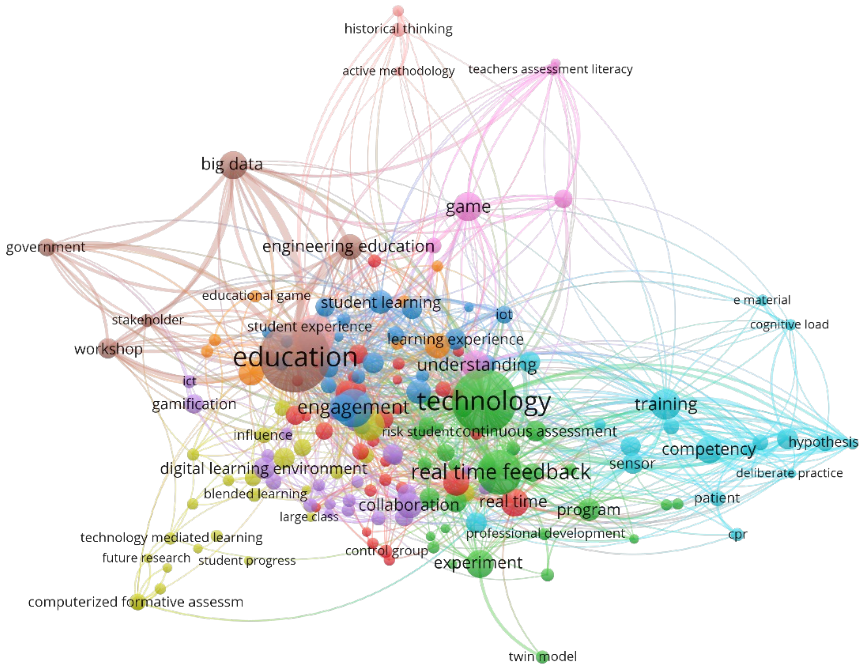

Figure 3. Clustering analysis to the semantic groups of keywords for the research topic of this paper.

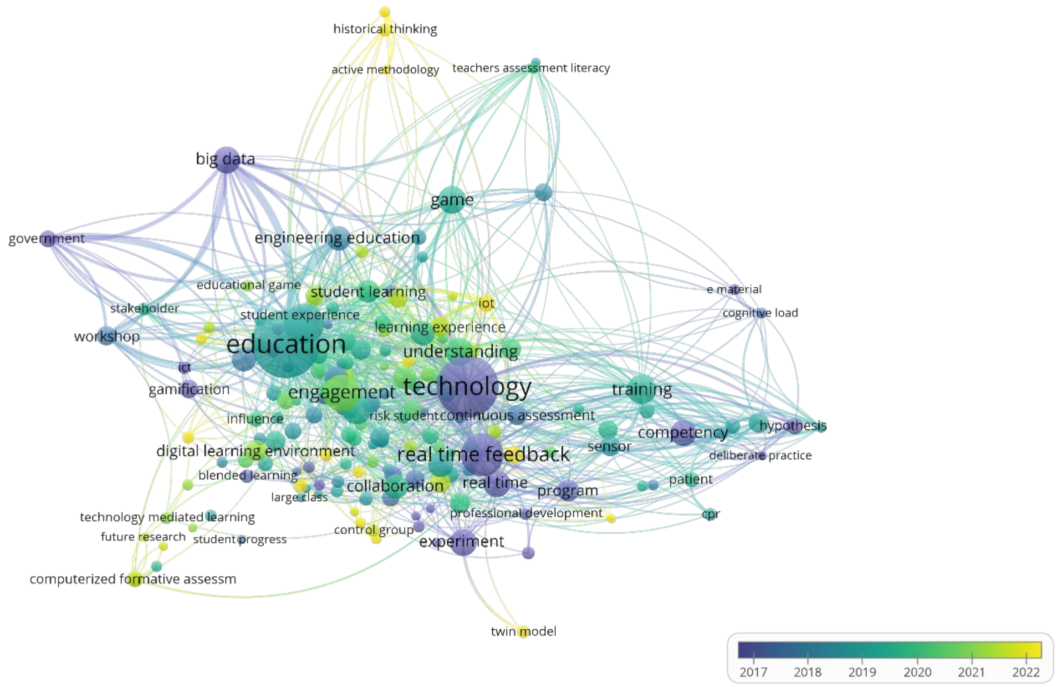

Figure 4. The overlay visualization shows where the last research was found between 2017 and 2022, meaning there are more dark, old research-related keywords.

Figure 4 shows where the innovation in research is in the research work related to this paper: i) historical thinking-based learning, active methodologies (peach color cluster on the top center), ii) technology in learning (AI), and iii) real-time feedback approach, this last one related to the topic of this work.

Problem statement and objectives of the strategy

To set a starting point, some of the challenges to be addressed with the implementation of an educational strategy to improve the teaching-learning process can be summarized in the following problem statement: "*The student must adapt to a high rate of information flow from the course theme that will be taught in 5 weeks, while maintaining motivation, attention, and developing skills, which in turn generate evaluation products reflecting their daily effort and commitment to learning. This poses an additional challenge to their learning*."

Aligned with the student's learning challenges, the educational strategy for improving the teaching-learning process aims to achieve the following objective: "*To facilitate the student's adaptation to the thematic context of the training unit, synthesizing the relevant knowledge to be retained, and thus homogenizing knowledge among students, encouraging them to pay attention and develop skills from the first day, where the results of their performance in the activity allow them to generate and reflect their effort from day one*."

Based on the previous issue, various hypotheses about this problem can be considered:

- *Hypothesis 1:* Students accept/perceive as more favorable to their learning/educational experience the continuous assessments of the methodology due to the short duration of the course in the same area (civil-structural engineering) for two different curriculum plans: Tec20 (semester-long in-person) vs. Tec21 (UF - 5-week block in-person), different courses but with the theme of the same area (civil-structural engineering).
- *Hypothesis 2:* Students accept/perceive as more favorable to their learning/educational experience the continuous assessments in the same remote modality for the same curriculum plan with the same course: Tec20 (semester-long remote) vs. Tec21 (summer/winter remote courses).
- *Hypothesis 3:* Students accept/perceive as more favorable to their learning/educational experience the continuous assessments in a different modality for the same curriculum plan with the same course:Tec20 (semester-long remote) vs. Tec21 (semester-long in-person).
- *Hypothesis 4:* Students accept/perceive as more favorable to their learning/educational experience the continuous assessments between shorter durations (semesters vs. months (summer/winter) vs. weeks-blocks) for various courses with themes in the same area (civil-structural engineering): Longer duration courses (semester) vs. shorter duration course (summer/winter/5-week block).

Description of the assessment strategy, scope, and limitations

The implemented tool consists of the following attributes:

- There are quick exams (quizzes) after the teaching session.
- The "quizzes" are conducted after an hour and 20 minutes of class.
- There can be session quizzes (up to 2 quizzes every 5 hours), weekly quizzes, and inter-session quizzes, which are taken and begin within a specific timeframe. For example, they open half an hour after the course and close half an hour before the next class.

- The quizzes have a 90% random component in their answers, meaning selecting one answer from several and simulation input values. As a result, students usually do not have the same input values.
- The time to solve quizzes is 20 to 30 minutes, depending on the difficulty.
- During the quiz-solving time, students have "almost" free interaction. They can talk but not share answers because they have different questions or input values. Also, the student must choose between interacting with someone else or solving the examination.
- The quizzes can be done at the beginning, mid-term, or end of the day's session. There is no specific time, and it will not be announced when they will happen, only that there will be a quiz at some point in the session.
- The quizzes have four difficulty levels: basic, intermediate, high, and expert. The difficulty level increased from day one to the last day of the course.
- Slides of the topics presented in class are not given before any quiz to encourage attention to the class. The quizzes must have simple questions, and when quizzes require more algebraic manipulation, the professor supports the student's task.

The following scopes and limitations will be considered:

- Limitation: The comparative courses are courses in civil engineering structures in the Bachelor of Civil Engineering.
- Limitation: The proposed indicators for assessing the proposed teaching methodology used an internal teacher assessment named ECOA, which stands for its Spanish acronym, Student Opinion Survey.
- Limitation: Using the ECOA’s metric, it is understood that it is a mixed set of metrics that include course satisfaction, teaching effectiveness, learning outcomes achievement, curriculum relevance, engagement and participation, resource and support services satisfaction, and practical skill development. Using the students’ grades as a performance metric could need a control population, and this could add the time dependence and contextual dependability from the topic’s state of the art and depth (through the curricula), professor skills, and students' generational context.
- Limitation: The indicators regarding the courses come from one professor for anonymity purposes required by the institution.
- Scope: Two curricula are included in this work. One is close to object-based learning, and it will be called Tec20. The curriculum Tec21 is Competence-PBL-based learning. The Tec20 chosen curriculum indicators from ECOA[1] are ETMET[2], ETEVA[3], and ETRET[4]; The Tec21 chosen curriculum indicators are EBRET[5] and EBREC[6]. These indicators come from the ECOA of the professor presenting the implementation of the educational innovation tool in the methodology mentioned later in this document.

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[1] ECOA = “Student Opinion Survey”

[2] ETMET = “Regarding the methodology and learning activities (provided me with clear and precise explanations, innovative means and techniques or technological tools that facilitated and supported my learning), the course was...”

[3] ETEVA = “Regarding the evaluation system (a set of tools was used that gave me feedback on my strengths and weaknesses in the course based on timely established policies and criteria), the course was...”

[4] ETRET=” Regarding the level of intellectual challenge (it motivated me and demanded my greatest effort and to achieve quality for the benefit of my learning and personal growth), the course was...”

[5] EBRET = “The teacher challenged me to give my best (develop new skills, new concepts and ideas, think differently, etc.) ...”

[6] EBREC=” In general, my learning experience with the teacher was…”

- Scope: Courses in Tec21 are called “block” or UF (Forming Unit) and take five weeks. Courses in Tec20 are summer or winter courses that are one-month intensive or semester courses.
- Scope/Limitation: The hypotheses are proposed to be accepted/refuted by comparing the mean (expected value) and standard deviation. Although this methodology is not strictly rigorous according to the theory of analysis and experiment design, no vast dataset and dimensions provide the scaffolding for these techniques and methods. Hence, the analysis is based on these parameters.
- Limitation: The indicators used by the study plan do not directly address the acceptance/perception of implementing the proposed tool/methodology but are indirectly related to each study plan.
- Limitation: As mentioned, indicators of the same course are compared, and the same course is compared in different curricula.

Methodology

Timing in the Application of Quizzes

At the beginning of the courses, the timeline of the course is presented to students (educational program in civil engineering, Tec21 curricula). It is verbally mentioned that the quizzes will come after an hour and 20 minutes of class and that this quiz will last 20 to 30 minutes. Just as the timing of quizzes is presented, a list of the number of quizzes, in which session they will take place, week, level of difficulty, allowed attempts, the prospective opening and closing time of the quiz (duration), points that will be obtained, and the weighting it will have in the total percentage contributing to the final grade is given to the student.

Students are informed that if the session needs to be extended due to exercises, tool use, or time extension, the quiz can be postponed and/or eliminated, stating that planning is only to keep class activities well organized. Initially, students are surprised by the number of quizzes they will take (“shock state,” to be more precise); however, after taking the first quiz in that session, they notice that the difficulty is low. It is proposed that there are four levels of quiz difficulty, see Figure 4.a:

- (15 points) N1- Basic level: random answers, four attempts, incorrect answers can be seen, and free navigation in the quiz is allowed.
- (20 points) N2-Intermediate level: random answers, three attempts, incorrect answers can be seen, and free navigation in the quiz is allowed.
- (25 points) N3- Advanced level: Random answers, two attempts, and incorrect answers can be seen; once answered, questions cannot be corrected.
- (30 points) N4—Expert level: random answers, one attempt, and questions that cannot be corrected once answered.

The existence of levels allows students to gradually adapt to the level during the first week's sessions. The intermediate level (N2) is introduced by the second week, and in the third week, N3, the block is finished at N4. They are told that having the highest level of assertiveness and effectiveness in facing the final exam is essential. It is mentioned that the final exam will be N4, which makes them aspire to the highest level of assertiveness about what they will do. In this context, assertiveness refers to:

- Student expression. Students should actively participate in quizzes without fear of judgment for wrong answers and see that mistakes are learning opportunities rather than failures.
- Self-assessment: Feel the quiz grade reflects the learning.
- Adaptability and improvement: Willingness to improve.

Consideration of Quizzes in the Final Grade

Quizzes, as tools for assessing and homogenizing knowledge among students, allow students to contribute to their final grade from the first session. In Figure 3, the image of a slide is presented to students showing that quizzes will contribute to their final grade and that it is necessary to take them; hence, attendance in class is not evaluated, but the completion of the quiz is, as well as paying attention to the class slides.

Additional rules, such as not allowing remote quizzes in face-to-face classes and requiring attendance, are set. It is also requested not to talk among peers, but talking does not lead to a reprimand or integrity violation, as they are under time pressure and must decide whether to help a peer or finish their quiz.

Students are informed that the final exam will contain all the questions from the quizzes, from 40 to 60. This initially makes them value reviewing and taking the quizzes and adds confidence to the final evaluation (final exam), knowing what is in it. Students are told that 15% of new questions will be added to the number of questions seen in the training unit. This adds a factor of uncertainty for the student who knows that there will be new questions in the final exam and keeps them studying and looking forward to what they will find in the final exam.

Results from the Application of the Teaching Strategy

The results of applying the methodology are summarized in tables A.1 and B.1 in appendix A and B, respectively. Four hypotheses were presented that should be analyzed based on the proposed indicators. Although the proposed indicators for each curriculum are not similar, they imply aspects of acceptance/perception of the methodology applied to the study plan.

- *Regarding hypothesis 1:* Students in the 2019 plan (Tec21) who take a 5-week UF rated a higher average of 9.6699 than the 2011 plan (Tec20) with an average of 9.6177. However, the standard deviation for (Tec21) was higher (0.3178) than for the (Tec20) plan (0.1457). In other words, and applying the central limit theorem, on average, students in 5-week blocks of Tec21 accept continuous evaluations more; however, there is more significant variability in this acceptance/perception, and consequently, although there is slightly lower acceptance in 2011 Tec20 curriculum, the reality is that there is not so much variability among students, so it can be concluded that in in-person modality there is no significant advantage in acceptance/perception in continuously evaluating for courses of the same area but different themes, regardless of the temporal difference of the semester and 5-week courses. The hypothesis does not seem entirely accurate with the metrics used because the mean acceptance/perception in the 2011 curriculum is lower than in the 2019 semester courses.

- *Regarding hypothesis 2:* For students in the 2011 plan Tec20 with precisely the same course remotely, there are differences in semester duration and short courses in summer/winter. Remote semester course students rate an average of 9.2437 (standard deviation of 0.8341) in acceptance/perception, while students in the short remote summer/winter course rate 9.7455 (standard deviation equal to 0.2247). This implies that continuous evaluation is seen better on average, with less variability in a short remote course than in a semester course. The hypothesis is verified from the metrics used.
- *Regarding hypothesis 3:* Students in the remote semester modality do not accept/perceive in the same way as students in the in-person semester modality. The former rate with an average of 9.2437 (sd = 0.8341) and the latter with an average of 9.6166 (sd = 0.1457). In the in-person semester modality, students accept/perceive continuous evaluations better for Tec20. The hypothesis can be said to be verifiable with the metric used.
- *Regarding hypothesis 4:* for the 2011 plan Tec20, in short-duration courses (summer/winter), students accept/perceive with an average of 9.7455 vs. 9.4302 for in-person and remote semester courses. It can be said that the shorter the duration, the greater the acceptance of continuous evaluations in short periods (approximately every hour and a half). The Tec21 model (2019 plan for UF as a 5-week block) has no comparison since it was only implemented in this block. Still, it has an average under its indicators of 9.6699, higher than the semester average (9.4302) already mentioned. It can be said that, under the indicators used, the fewer weeks the course has, the perception/acceptance of continuous evaluations is, in that order, summer/winter courses (4 weeks – 9.7455), blocks (5 weeks - 9.6699) and semester (18 weeks – 9.4302).

Conclusions

Based on the hypotheses proposed, the evaluation indicators, and the analysis of the results, it can be said that the application of the proposed methodology to homogenize knowledge using immediate, contextual, and adaptive evaluations for courses in Structural Engineering of the Civil Engineering program allowed positive results in the learning and teaching processes. It also helped create a positive perception of the courses in the student satisfaction surveys. It engaged students with the content of the courses that have traditionally been difficult to motivate, as is the case for Structural Engineering courses.

Another significant result is reducing and simplifying marking for professors, providing immediate feedback for students and their performance in the course. The authors consider that the model presented in this work can be helpful in courses from many other disciplines, not only Structural Engineering within the civil engineering curricula.

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Appendix A – Results tables for the (name hidden for reviewing) model

Tabla A.1. Indicators taken of (name hidden for reviewing) model									
Num. of application NAP	Course	Year	Type of course	Semester	Model	Modality of teaching	ETMET	ETEVA	ETRET
1	Design of Steel Structures	2022	Semester	Feb-Jun	[redacted]	In-person	9.33	9.54	9.67
2	Design of Steel Structures	2022	Summer	Jun	[redacted]	Remote	CHI 10 GDL 10 MTY 10 PUE 10 S-NTE 10 TOL 9.5	CHI 10 GDL 10 MTY 9.88 PUE 10 S-NTE 10 TOL 9.0	CHI 10 GDL 10 MTY 9.75 PUE 10 S-NTE 10 TOL 9.5
3	Design of Steel Structures	2022	Semester	Aug-Dec	[redacted]	Remote	CDM 9.5 EDM 9 GDL 9.33 LAG 7 MTY 9.33 MOR 9.75 PUE 9.57 QRO 6.67	CDM 9.5 EDM 9 GDL 10 LAG 7 MTY 9.44 MOR 10 PUE 9.71 QRO 8.67	CDM 9.5 EDM 9 GDL 10 LAG 8 MTY 9.33 MOR 10 PUE 9.71 QRO 9.0
4	Design of Steel Structures	2022	Semester	Aug-Dec	[redacted]	In-person	QRO 9.69	QRO 9.71	QRO 9.76
5	Design ofB.1Steel Structures	2023	Winter	January	[redacted]	Remote	GDL 10 MTY 10 PUE	GDL 10 MTY 10 PUE	GDL 10 MTY 10 PUE
6	Design of Steel Structures	2023	Semester	Feb-Jun	[redacted]	Remote	GDL 9.00 QRO 9.20 CHI 10 MOR 10 PUE 9.75	GDL 8.33 QRO 9.60 CHI 10 MOR 10 PUE 9.75	GDL 9.33 QRO 9.20 CHI 10 MOR10 PUE 9.0
7	Design of Steel Structures Diseño de estructuras de acero	2023	Summer	Jun	[redacted]	Remote	MTY 10	MTY 10	MTY 10
Semester - Remote course (mean and standard deviation)							9.0846 (1.0525)	9.3076 (0.8754)	9.3391 (0.5745)
Summer/Winter course - Remote (mean and standard deviation)							9.4444 (0.1667)	9.8755 (0.3307)	9.9166 (0.1767)
Semester – In-person course (mean and standard deviation)							9.51 (0.254)	9.625 (0.1202)	9.715 (0.063)
Remote national courses in other campuses (GDL, QRO, CHI, MOR, PUE, MTY, TOL, S-NTE, LAG, EDM, CDM)									

Appendix B - Results tables for the (name hidden for reviewing) model

Tabla B.1. Tabla A.1. Indicators taken of (name hidden for reviewing) model								
Num. of application NAP	Course	Year	Type of course	Semester	Model	Modality of teaching	EBRET	EBREC
8	Assessment of the behavior of materials in Structures	2022	Block Five weeks	Feb-Jun	[redacted]	In-person	9.85	9.81
9	Structural Design of Reinforced Concrete and Steel Structures	2022	Block Five weeks	Feb-Jun	[redacted]	In-person	10	9.93
10	Assessment of the behavior of Structural Systems	2023	Block Five weeks	Aug-Dec	[redacted]	In-person	9.9	9.76
11	Assessment of the behavior of materials in Structures	2023	Block Five weeks	Feb-Jun	[redacted]	In-person	9.9	9.7
12	Structural Design of Reinforced Concrete and Steel Structures	2023	Block Five weeks	Feb-Jun	[redacted]	In-person	9.46	8.71
13	Innovation in materials and constructive process	2023	Block Five weeks	Ago-Dic	[redacted]	In-person	9.42	9.50
14	Assessment of the behavior of Structural Systems	2023	Block Five weeks	Ago-Dic	[redacted]	In-person	9.74	9.70
In-person course (mean and standard deviation)							9.7528 (0.2275)	9.5871 (0.4081)