The Digital Transformation of Structural Analysis Courses: Implemented Changes in Recent Years

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Abstract

This paper presents the various models implemented in Structural Analysis courses at our university Tecnologico de Monterrey over the past eight years, encompassing a total of 300 students. Structural Analysis courses are known to be challenging for Civil Engineering and Architecture students, and in recent years, due to global disruptions such as the COVID-19 pandemic, the way these courses are taught has changed significantly compared to nearly a decade ago. Initially, a model was introduced that involved using a YouTube channel as a repository for lecture materials presented by professors. Additional changes included using diverse learning spaces on campus for class sessions, including a room we designated as the Innovate Room.

With the onset of the pandemic, all courses transitioned to an online format, utilizing digital communication platforms like Zoom. This sudden shift accelerated the digital transformation of both the course content and the learning dynamics between students and professors. The model was adapted for online learning while maintaining a student-centered approach. Once students returned to campus, the model evolved further, incorporating hybrid learning sessions and asynchronous materials to complement the course structure. Over the past three years (or six semesters), these courses have been aligned with our university's new educational model Tec21, which is a competency-based, student-centered approach. Within this framework, a challenge-based methodology was introduced, coupled with modifications to the existing hybrid model.

This paper highlights the results from the past fifteen semesters, during which a continuous digital transformation of traditional Structural Mechanics courses has been applied. The findings demonstrate steady improvements in student satisfaction and pass rates. The paper also explores the types of activities students preferred during these terms, along with their perceptions of how Artificial Intelligence tools could be integrated into future iterations of the course model. Moreover, a discussion is provided on students' views regarding the future of universities and academic courses in a post-pandemic world.

We present these results to illustrate how a highly theoretical course, such as Structural Analysis, can greatly benefit from the integration of digital transformation elements. The evidence suggests that these changes have had a positive impact not only on the course's learning outcomes but also on student motivation. Furthermore, we believe that the lessons learned from these adaptations could be applied to other courses and undergraduate programs, particularly those where student engagement is low, and where a course redesign might yield similar positive outcomes.

Introduction

During the last few years, many changes have been implemented in higher education around the world. Many of the changes were accelerated by the global pandemic of 2020-2021 and had to do with the adoption of online education in most institutions that were able to offer that option almost immediately after the beginning of the pandemic. The sudden change of format for most educators implied that they had to adapt very quickly to the online sessions and, most importantly adapt their courses' contents [1]. On the other hand, the sudden use of internet at all educational levels in many countries created new

problems for governments and education institutions, since their infrastructure might have not been ready for such use. The readiness of their systems for digital transformation was also measured in some cases [2] and in some other cases, the pandemic accelerated such transformation [3]. Digital transformation can face challenges and it could even be a failure in some organizations when they try to implement abrupt changes [4-9].
In the case of Engineering courses that can be difficult for the students and professors due their complexity, some efforts can be done to include the latest technologies to motivate new generations and keep their attention throughout the course. In some cases it could be easier to convince the students that changes are necessary than convincing traditional professors or instructors [10].
In this work we present a series of changes implemented to the way courses of Applied Mechanics were taught to students of two main programs: Civil Engineering and Architecture students. These courses are part of their curricula and have to be taken between the third and fifth semester of each program.
The decision to implement changes had to do with the motivation of students shown in past years and their passing rates that were low. Several of the changes introduced started to revert the trend on passing rate and were very well accepted by students. Another point on why there were changes in the course format had to do with the change of educational model in our university. As of this year, we have now a competences-based model for all programs. This new model is a student-centered model and it also makes use of the latest technological advances for the classroom.
Also in this work, some results of the perception of students about each new element in the course will be shown. Some changes had to do with “hardware”, for instance, new furniture and new classrooms whereas other changes can be grouped as “software” changes, including the use of computer programs or applications for the telephone, including the encouraged use of YouTube in the classroom or the use of Artificial Intelligence tools, as some recent publications present their use and usefulness in the classroom [11-14].

Methodology

In the past few years, our university has implemented a new education model, namely Tec21. As mentioned before, this model is a competences-based model and it is also student-centered. The use of the latest technologies in the classroom is motivated through the solution of challenges. The students that took the courses included in this paper come from two programs: Bachelor in Architecture and Civil Engineering. The courses selected for this study are:

- Mechanics of Structures II
- Structural Systems
- Structural Analysis (Computational)

These selected courses are in second and third year for Civil Engineering students and in the third year for the Architecture students. The distribution of both programs in the groups were nearly 50% each, with 53% of students from the Architecture program and 47% from Civil Engineering one.
In these two programs, the use of technological tools such as Building Information Modeling (BIM), Project Management computer programs are very common in other subjects but for mainly theoretical courses like the ones related to Applied Mechanics Courses, their use can be limited. We have seen that when students get to use some computer programs and applications, their motivation in the course is higher. Other didatic techniques have also been tried, such as problem-based learning and challenge-based learning to increase student motivation, see for instance [15-19]. With new virtual environments appearing every day, even universities are experimenting with the so called metaverse [20].

A total of 300 students answered a survey at the end of several terms in which one of the three-courses was taught. The terms considered for this paper are, with the description of the format for each one:

- Spring Semester 2018 (on campus)
- Autumn Semester 2018 (on campus)
- Spring Semester 2019 (on campus)
- Autumn Semester 2019 (on campus)
- Spring Semester 2020 (online)
- Autumn Semester 2020 (online)
- Spring Semester 2021 (hybrid)
- Autumn Semester 2021 (hybrid)
- Spring Semester 2022 (on campus-hybrid)
- Autumn Semester 2022 (on campus-hybrid)
- Spring Semester 2023 (on campus)
- Autumn Semester 2023 (on campus)
- Spring Semester 2024 (on campus)
- Autumn Semester 2024 (on campus)

Timeline of changes

In Fig. 1 we can see a timeline of the several major changes introduced to the courses in the last few years, which will be described below:

- 2016 Introduction of YouTube channel as a tool for the courses. One of the professors would record every session and upload daily videos to the channel. So far, the channel has over 700 videos related to the courses. Every semester a new set of examples are solved, so that the repository increases the number of videos for each topic.
- 2018 A new classroom was used (see Fig. 2). This location was new on Campus and was selected for the classes. As it can be seen, there is enough natural light coming from one side and the other three walls had independent video projectors, so different material can be projected in each of the four projectors. This helped in cases in which a table was needed for a certain problem and the formulas could be displayed in another one, while the professor could be solving "live" a problem in a different whiteboard. The chairs are rotating Steelcase chairs that allow students to move freely in the classroom, particularly good for team-work. This room is called the "Innovate Room".
- 2019 New educational model introduced in our university, which is a competences-based model.
- 2020 Online courses due to Pandemic measures. For many professors and instructors it was the first time teaching online.
- 2021 Hybrid Teaching on campus: the gradual return to campus implied reduced class sizes and combining the face-to-face interaction with online videoconferencing.
- 2023-present The use of Artificial Intelligence tools in the classroom started and continues to grow.

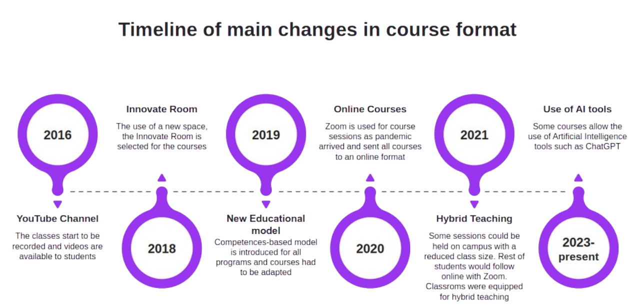

Fig. 1 Timeline of implemented changes in the course format

Fig. 2 The Innovate Room, in 2018. Notice the four projectors and three whiteboards on the walls.

Student-centered model

All the changes introduced to the courses, including the new educational model are meant to have a student-centered model. In Fig. 3 we can see the different tools or techniques available to students during the courses: the standard course materials such as presentations, lecture notes, available trhough the platform Canvas, they can also use for their assignments and projects the facilities on campus for video production, the YouTube Educational Channel with hundreds of videos, the Structural Mechanics Laboratory and tutorials with their professors that can be face to face or in Zoom. We call this the “hardware and software” available to students. The combination of all this factors have made a positive impact in the performance of students, as it will be shown in the following sections.

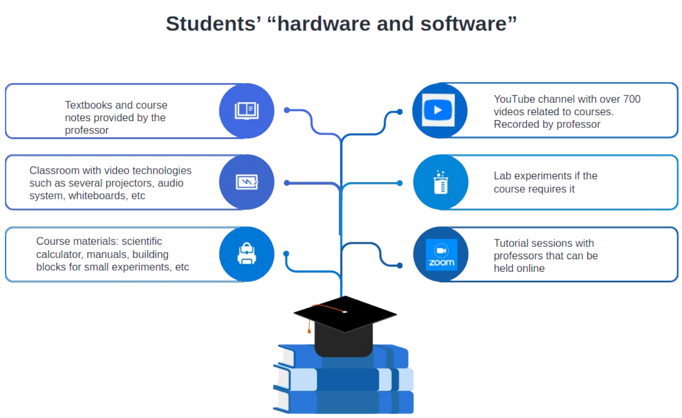

Fig. 3 Different tools and technologies available for students

The evolved teaching model

igure 4 shows the flowchart that is used for most sessions of a course. This model has been evolving from the very beginning of the introduction of the YouTube channel as a tool. Basically, the steps are as follows:

(1) What Type of Session we have today?

a) Theoretical Session

b) Assignment/Homework/Challenge Session

(2) Theoretical session. These sessions substitute the lecture sessions of past models. In this one the professor can introduce live a topic or might go for asynchronous material, such as videos recorded by the professor in a different term. They can make up to two-thirds of the total sessions of the course.

(3) Assignment/Homework/Challenge Session: Students work in teams to start preparing their solution to the challenge or the solution to a given assignment. It includes team work. These sessions can be up to one-third of the total number of sessions in the classroom.

(4) Assignments for the Digital Transformation: Students work on set of problems, a beam-design or research papers on the biography of certain important engineer or researcher such as Euler or Castigliano. Artificial Intelligence tools such as Google Assistant or ChatGPT can be used to research historical facts but not for the the solution of problems.

(5) Did student attend the session?

a) Yes, and student needs more help. Then it should make an appointment to meet professor online. If student is confident on the topic and considers that no more help is needed then she/he can proceed to solve the assignment.

b) No, the student did not attend the session. Appointment with professors is advised. Meeting the professor is not compulsory but it has proven to be of great aid when missing a theoretical session and they need more help after watching the video of the session.

(6) Students work in teams on their assignments or the solution of the challenge.

(7) Repeat steps 1-6 until the end of the term.

The sessions can also be flipped-class sessions where the use of the Educational YouTube channel is very important. In some cases, particularly when the professor is attending a conference, the session could be live on Zoom.

This teaching model is an evolution of several years of changes implemented in the classroom, as mentioned previously and shown in Figs. 1 and 3, always moving towards the digital transformation of the course.

Results

The results of the survey that students answered and also the statistics of the grades show that the changes implemented in the recent years have had a positive impact in student satisfaction as well as in their performance in the course. In the following sections we will show the results of different aspects of the changes and what students’ perceptions are for some of them.

Results on Students’ Digital Transformation

Some of the assignments during the term have to do with producing some videos explaining certain topic or solving a given problem. In other cases, students have to present using Zoom or any other videoconferencing tool. At the end of each term students were asked if in their perception they considered to have the competence of communicating their ideas using digital media. Fig. 5 shows the results of the question if students considered, in their perception, that they have further developed their competence of communicating their ideas using digital media after the course. 82.91% considered that they did improved, 14.18% were not sure about it and only 2.91% answered that they did not improve this digital competence.

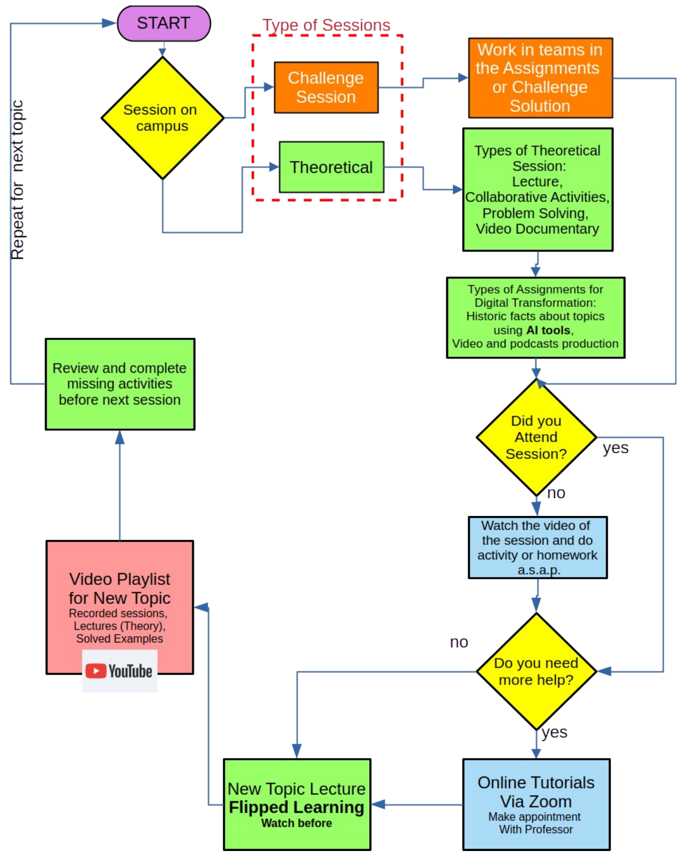

Fig 4 The Hybrid Teaching Model Flowchart. 2025 Version

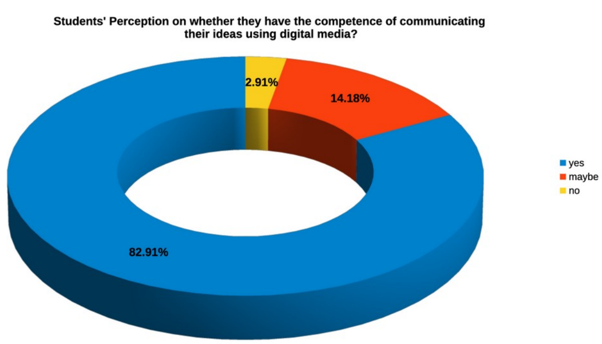

Fig. 5. Students' perceptions on whether they improved the competence of communicating their ideas using digital media

Another question was asked about what digital competence they developed the most during the term. Fig. 6 shows the result of this question, with 60.7% choosing “Effective oral communication using digital media”, 32.10% answered “Effective communication using videos”, 3.60% selected “Effective oral communication using podcasts” and the same percentage. 3.60% also chose “Effective oral communication using messenger apps such as Whatsapp or Zoom chat.

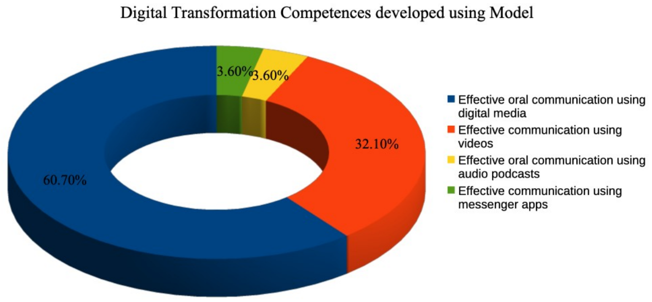

Fig. 6. Students’ perceptions on what Digital Transformation Competences they developed in the course

In the last year, the use of Artificial Intelligence tools has increased in our courses. Professors do not forbid the use of such tools but make clear their limitations when dealing with Engineering problems. In our courses the AI tools have been used mainly to help get the students more context on a particular famous Engineer or method. At the end of the course and after some interaction with such tools, students were asked what they would think the future will bring in terms of AI applications in the field of Civil Engineering. Fig. 7 shows the results of their answers. Over thirty percent (30.18%) considered that Project Management will be the main use of AI tools for Civil Engineering, 20% thought about Engineering Design as the main use for AI, 19.64% of students considered Maintenance and Failure Detection and 9.82% selected “other” as the main application of AI in Civil Engineering practice.

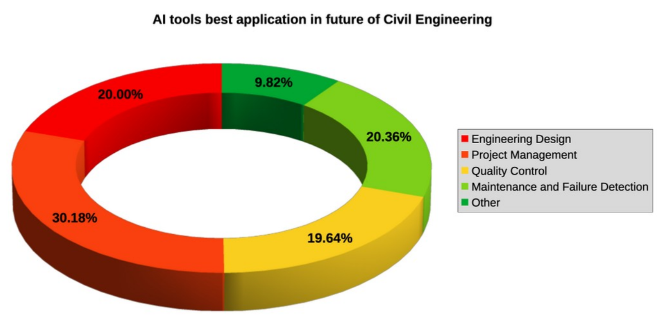

Fig. 7. Students’ perceptions on what would be the best use of Artificial Intelligence tools in Civil Engineering practice

Improvements in Student Satisfaction

In recent years, student satisfaction has become an important indicator for universities around the world. Although it is not the main objective of the changes implemented in the courses, it is a positive side-effect. For every course in our university we have an end-of-course survey in order to get the opinion of the students on many aspects of the courses. One important question is the "recommendation" they give of a course with a certain professor. We call this indicator "REC" as an acronym for recommendation. The scale is a likert scale from 0 to 10, where 10 is the best possible mark. Fig. 8 shows the result of this question for one of the authors, as the main professor of a course for the last six terms. It can be seen in the graph that the recommendation has steadily increased, coinciding with the innovations or changes introduced in the course.

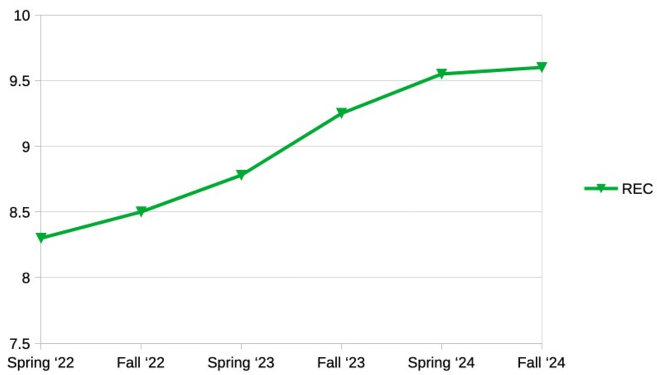

Fig. 8. Professor's RECommendation in the students' survey at end of the last six terms.

In the survey of this work that students answered each of the considered terms, there was a question on how satisfied they were with the course and the implemented changes. Fig. 9 shows the results, with over ninety percent (90.55%) of "very satisfied" answers and only 9.45% giving a neutral answer with no answers for "not-satisfied".

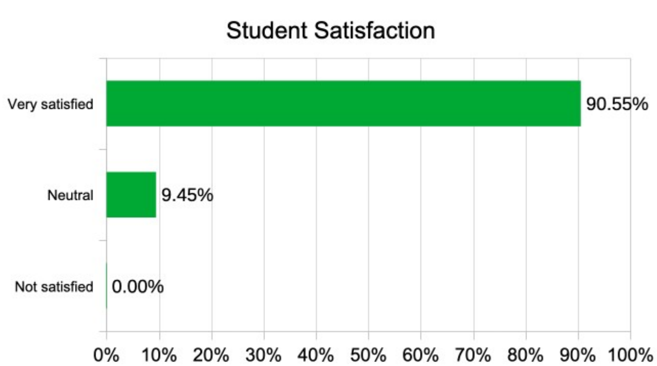

Fig. 9. Students' satisfaction with the model of the course.

Improvements on Students' Performance

As the changes have been implemented in a several years period, it was important for us to measure the impact it had on the performance of students and how they perceived those changes were positively impacting their performance. Fig. 10 shows the perception of students regarding the improvement in their grades. Over twenty-five percent (25.64%) considered that the tools such as the video repository in form of a YouTube Channel has helped improved their grades at least 20% if they were to compare the course without the available tools. 38.46% considered that the model and its tools have helped them improved up to 20% their final marks, 30.77% think that the model might have helped them improved their marks up to 10% and 5.13% considered that the model has no influence in their performance.

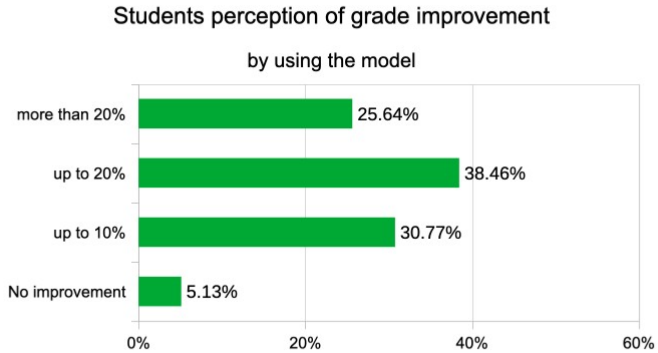

Fig. 10. Students' perception of grade improvement with the model

Finally, it is important for professors to see if the motivation of students increased, resulting in better passing rates for the group of students. Even if every generation is different, it is important to see a positive trend when a change is introduced. Fig. 11 shows the results of passing rates for the courses for the last ten years. In different colours we can see changes introduced in the courses. For instance in yellow, in 2016 the YouTube model was introduced and the effect was immediate, as the passing rate went up from 71% to 80%. In green bars we can see the effect of moving the courses to a more modern classroom, the innovate room, with passing rates going up to 89%. Then the Covid19 pandemic arrived and courses had to go online but results remained more or less at the same level around 94%. Then it started to decrease as the motivation was getting lower in students since the return to campus happened only in 2022, and you can see that the motivation helped students return to passing rates over 95%. With the introduction of a challenge-based model in spring 2023, and with more team-work, passing rates reached even 100%, and oscillated between 92% and 96% for the last two terms in 2024.

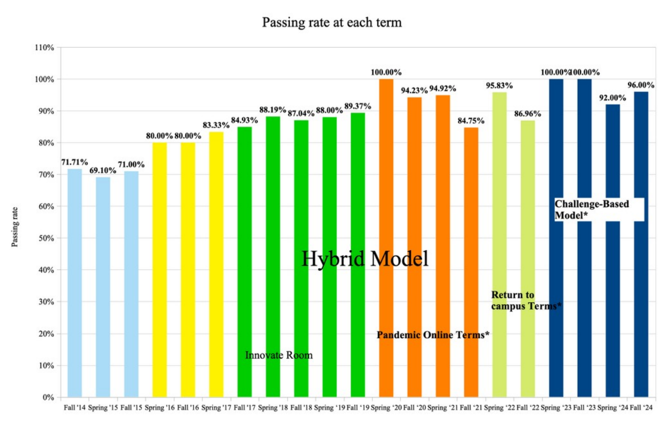

Fig. 11. Students' perception of grade improvement with the model

Conclusions

In this work we have presented a series of changes implemented in Applied Mechanics Courses in the recent years, including changes in the campus facilities used for the courses and some structural changes in the educational model, such as the introduction of real challenges and the interaction with an industry partner.

The perception of students regarding the use of several tools in the course was also presented. In general, students have received the changes very well and results in their performance and their recommendation of the professor and course in the students' survey show that the change have had a positive impact in student satisfaction and performance, in particular, the positive effect on the passing rate for each group is an indicator of the overall impact of our model.

As more and more AI tools appear every day for different uses, it will become nearly impossible for educators around the world to ignore their presence. We believe that our task as professors is mainly to help students identify what is a valid use and the risks of using such tools for Structural Design if the engineer is not properly prepared to be able to select a good solution from a spurious one.

We present this work and our experience with several changes introduced in our courses so that other colleagues around the world could improve their courses with some of the elements presented in the previous sections and, therefore, improve the student motivation and satisfaction of the so called "difficult" or "too-theoretical" Engineering courses.

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