2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #37944

A Challenge-Based Specialization Diploma on Structural Health Monitoring for Civil Engineering and Architecture Programs

Saul E. Crespo, Tecnologico de Monterrey, Mexico

Bachelor in Civil Engineering with a Master of Science in Structural Engineering and PhD candidate in Structural Engineering. From April 2011 to July 2017 he served as Senior Researcher of the ”Structural Health Monitoring” group of the Mexican Institute of Transportation, directing and collaborating in monitoring and structural prognosis projects applied to special highway bridges, transportation infrastructure, historical monuments and structural systems. He has developed research projects in the area of structural deterioration of reinforced concrete bridges and in the development of damage detection techniques in structural systems based on Non Destructive Evaluation. He actively collaborated in the creation and development of the Monitoring Center for Intelligent Bridges and Structures, leading the analysis and structural evaluation of the systems. In the academic field, he has worked as a professor in the Civil Engineering career, in the area of structural engineering at the Instituto Tecnológico de Estudios Superiores de Monterrey (ITESM) Campus Querétaro. He has directed research projects for undergraduate and master's degree students. He has authored several technical publications of the Mexican Institute of Transportation, extensive publications in congresses, international and national symposiums, as well as in scientific journals. From 2017 to 2020 he served as Director of the Civil Engineering program at Tecnológico de Monterrey Campus Querétaro and as professor of the Structural Engineering area at the institution and since November 2020 he leads the Department of Sustainable Technologies and Civil Engineering at Tecnológico de Monterrey Campus Querétaro.

Prof. Miguel X. Rodriguez-Paz, Tecnologico de Monterrey, Mexico

Prof. Rodriguez-Paz got his B.Sc. In Civil Engineering from Tecnologico de Oaxaca in 1993. He studied a M.Sc. In Structural Engineering at Tecnologico de Monterrey and got his Ph.D. from the University of Wales at Swansea in 2003 where he did research on Numerical Methods. Since 2004 he is a full professor of Engineering Mechanics at Tecnologico de Monterrey.

Job R. Medina Hernandez, Tecnologico de Monterrey, Mexico
Ing. Luis Horacio Hernandez-Carrasco, Tecnologico de Monterrey, Mexico

Civil Engineer Master degree in Structural Engineering Master in Business Administration Full time professor at (Tec de Monterrey) ITESM Professional Registered Engineer in Structural Design

Prof. Milan Sokol, Slovak University of Technology in Bratislava, Slovakia

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Abstract

In this paper we present a challenge-based teaching model for a full semester of specialization in the Civil Engineering program in our University. In this minor or specialization diploma, students develop competencies associated to Structural Health Monitoring (SHM), Instrumentation and non-destructive testing of Structures.
During a ten week period, several modules are taught to students with material about Civionics, SHM, damage detection in Structures, non-destructive techniques and Load testing of real structures. For this purpose a on campus bridge was instrumented with sensors for deformation, inclinometers, accelerometers and displacement sensors. A total of 31 students took part of the first implementation of this specialization semester from two different campus in a regional format with activities in two different locations. The instrumented bridge was tested using a designed experiment with loading tests. The data acquired during the tests was then analyzed by students and it was used to calibrate a Finite Element Model of the bridge in order to evaluate its structural health state. Six different instructors and professors participated during different modules of the semester, some in laboratory tests and others in lectures and research. The educational outcomes sought during the design of this specialization semester were achieved with very positive results that are included in detail in the paper. As an strategic industry partner, a collaboration agreement was signed with the Mexican Institute for Transportation (IMT). The participation of specialists from this Federal Institute was crucial in the motivation and teaching of some modules of this program. Some specialized equipment from IMT was also used by the students for some experimental work associated with the theoretical aspects taught on campus. The results show that the competencies level that were sought during the design of the program were positively achieved by the students. We present this work that could be use as an example of Challenge Based courses or Specialization semesters for other minors within the context of Civil Engineering or Architecture Programs.

Introduction

Our Educational Model namely Tec21 is a competence-based model and it is a student centered model [1-5]. These competences can be disciplinary competences or transverse competencies, e.g. soft competences such as collaborative work. In every course students have to solve challenges or real life scenarios that are related to the situations they will face in industry once they have graduated. For this reason, every challenge is associated with scenarios that provided by industry, society through non-government organizations, local governments or research centers. All these entities are called Strategic Forming Partners (SFP).
The structure of the educational model is distributed basically in four basic elements: Subjects (courses), Blocks (challenge-based courses), i-weeks (short disciplinary courses, one week in length) and One semester minors or concentrations (students get a diploma after successfully finishing it). Each Engineering program has a different curricula design but they all use these elements in more or less the same manner. In this

work we will share the experience of a one semester minor or professional concentration diploma for the Civil Engineering Program, namely: Efficiency and Digitalization of Construction Industry. This diploma is also available for Architecture Students.

In our model this Professional Concentration semesters take place in the seventh semester of an eight semester program, as it is the case for the Civil Engineering Program. The main objective of these semesters is to introduce students in a new curricular line that is modern and attractive to students and, at the same time, responds to the future needs of the industries that hire our Civil Engineering graduates. Its length is a full semester in which students have to solve a challenge related to the applications of the theory and procedures learned in class.

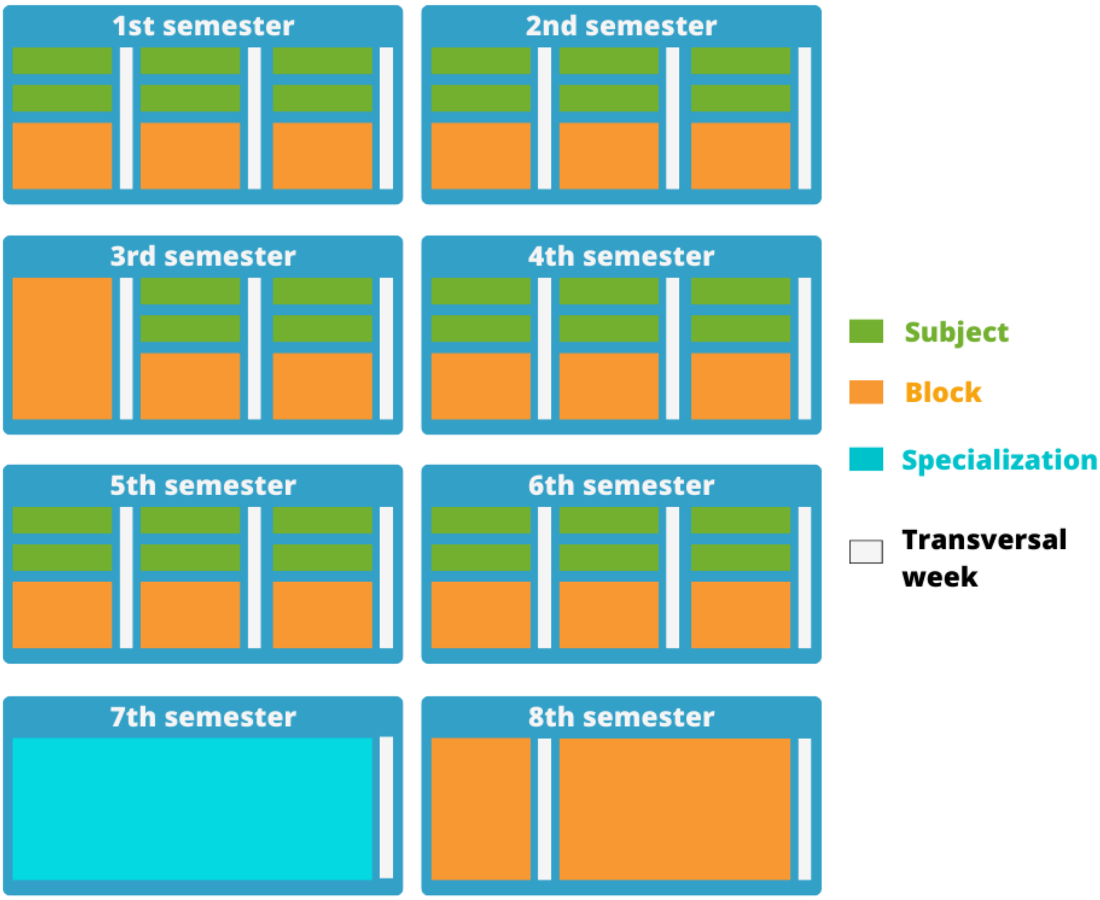

Fig. 1. Structure of the Civil Engineering Program

In our Civil Engineering Program, there are three different Professional Concentration Diplomas: Sustainable Water Usage, related to current water problems in cities, from water reservoirs to the design of water networks and the treatment of waste water. Second one is related to Real State Intelligence, focus in project planning and some urban design and the third one is the one presented in this work: Efficiency and Digitization of Construction Industry in which some techniques of virtualization of projects, Building Information Models (BIM) [6-7], as well as the development of new projects and new intelligent infrastructure with the implementation of sensors and modelling of new or existent projects.

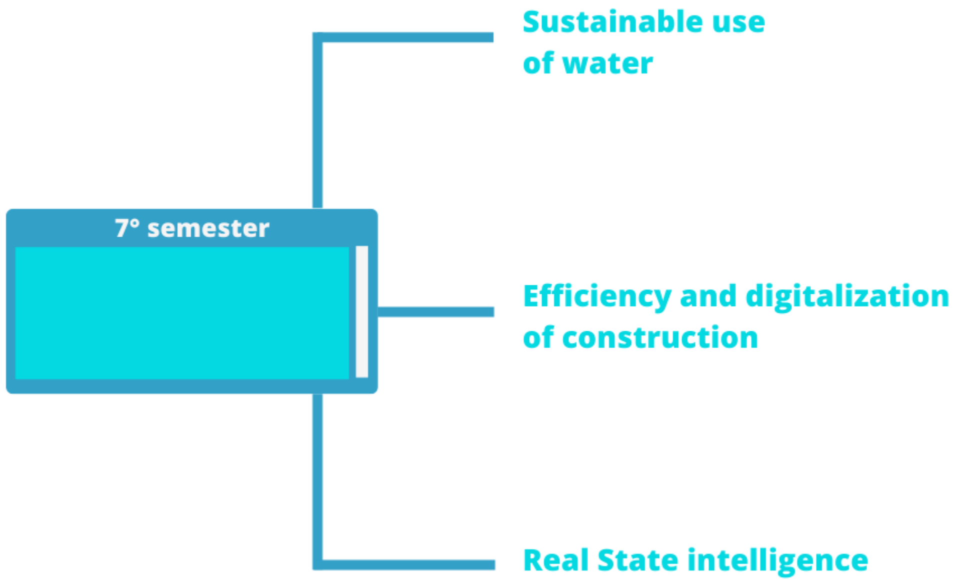

Fig. 2 Professional Concentration Diplomas for Civil Engineering Program

The concentration semester “Efficiency and Digitalization of Construction Industry” has two courses in the modality of block. The first one with a duration of five intensive weeks deals with topics on Optimization, Building Information Modeling (BIM) techniques and some topics on Lean Construction. In the second one, there are four modules: Introduction to Civionics, Non-destructive Techniques, Structural Damage and Retrofit, as well as Structural Loading Tests, as shown in Fig. 3.

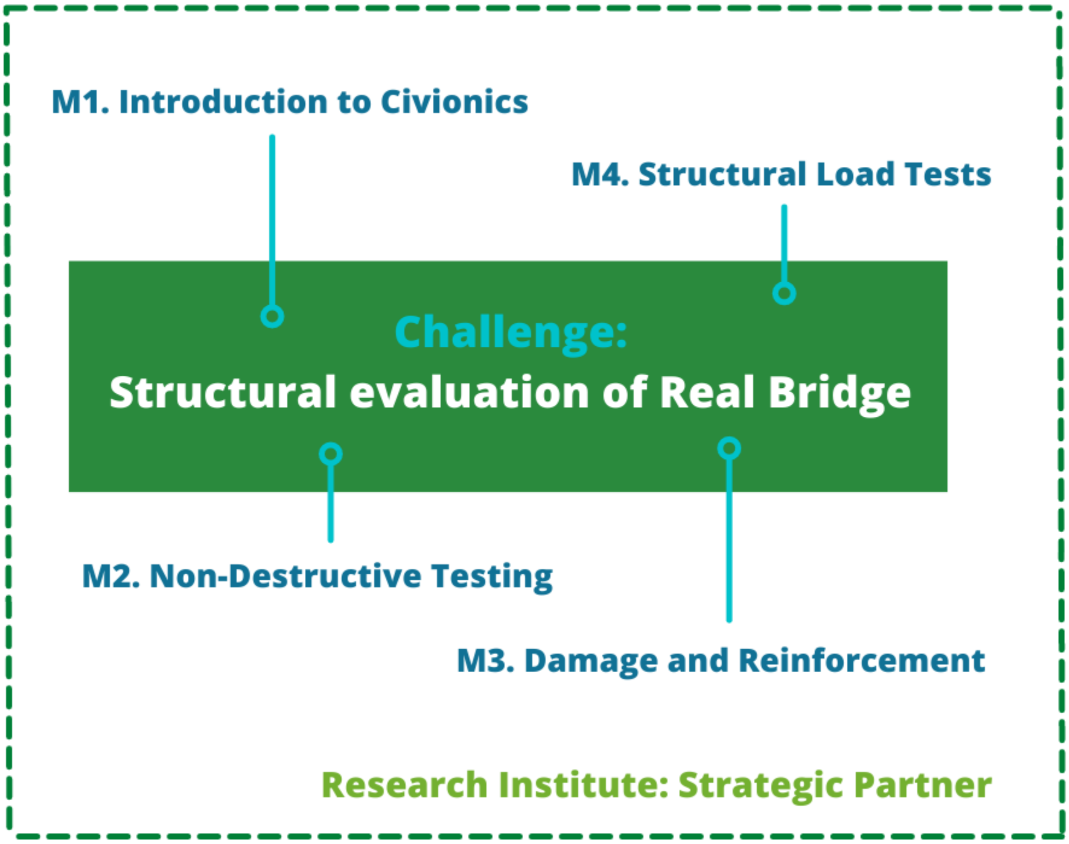

Fig. 3 Topics of the Concentration Diplomas

This Concentration Diploma was taught in a hybrid format (see Fig. 4) so that students from two different campuses could join the sessions. Students were in Campus Puebla and Campus Queretaro, including students from Civil Engineering and Architecture programs. The SFP for this diploma was the Mexican Institute of Transportation (IMT).

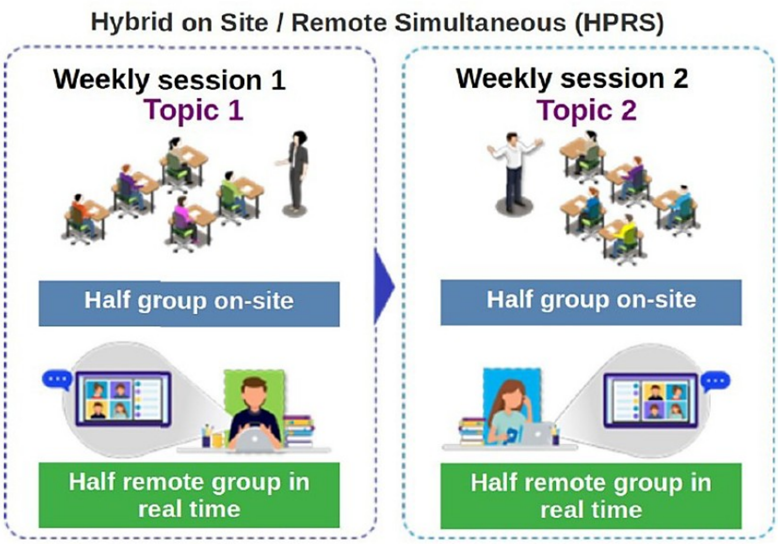

Fig. 4 Hybrid Model used for the semester

For the development of the challenge and its solution a real structural system was chosen with the main objective of applying the techniques and methodologies seen in the classroom in the different topics. Given the complexity of this task and the inherent risks associated with working in heights and in road bridges, a pedestrian steel bridge located inside one of our campuses was selected for the different experiments the students would design and test. The bridge has a minimal degradation state at some points (see Fig. 5).

Fig. 5 Steel bridge in Campus BBBB.

In the PCD, in one of the first modules some geometric modeling techniques and the virtualization of infrastructure using radar technology were taught. In order to get the students some practical work, some buildings of both campuses were surveyed using a 3D scanner. These practical demonstrations allowed the students to get familiar with digital models and to apply the theoretical concepts seen in class.
Some of these actitivies included the preparation of a digital model of a building from a cloud of points surveyed by the scanner and using specialized software, students were able to complete a model of a given building. Professors and lab instructors helped the students with explanations on how to operate the scanner and the specialized software, as shown in Fig. 6.

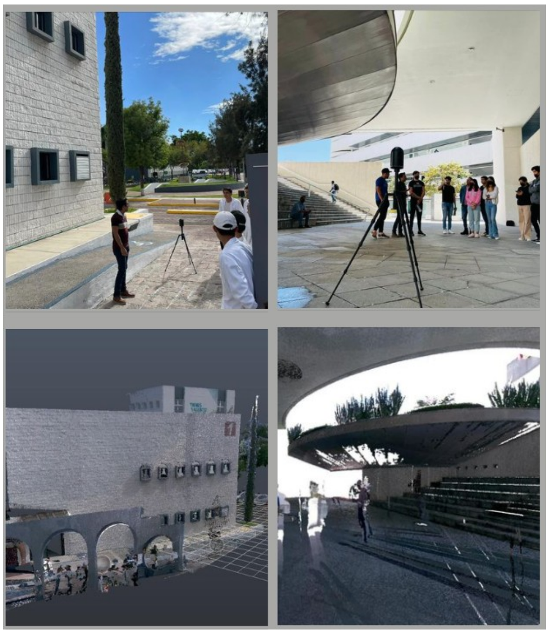

Fig. 6 Preparation of a digital model of a building using a 3D scanner

The second module included the evaluation of structural elements using non-destructive techniques, such as ultrasound, acoustic emissions and penetrating liquids. For these topics, our SFP, the Mexican Institute for Transportation prepared a set of pieces from cable bridges, particularly the fastening components that were taken for inspection. Our students were able to detect the cracks and internal damage in the pieces and they also applied non-destructive techniques to some elements. The testing and experiments were guided by professionals of the Institute (IMT) and were designed according to the standards they use for their projects. In this manner, our students applied the contents of this module to elements that were part of a real project, as seen in Fig. 7.

In modules three and four of our PCD, the topics included Sensors Engineering and its application to Structural Health Monitoring (SHM). For these modules, some experiments were done in the lab and some in the bridge, in which students from both campuses installed displacement sensors, extensometers and inclinometers on different structural elements. With these practical activities students developed competencies in the installation, data acquisition and data monitoring. During this phase of the semester, professors and lab instructors guided the experiments with static and dynamic loading in different structural elements. Students were able to observe the structural element behaviour in practice and then, develop some data analysis using some coding and data visualization in Python and Matlab (Fig. 8).

Fig. 7 Experiments of non-destructive tests at the National Institute for Transportation

After the students finished some theoretical modules in the classroom and had some experience with the guided experiments, they started the solution of their challenge. First step involved the geometric modeling of the steel bridge in campus. This was done using a 3D scanner and specialized software to handle a cloud of points captured by the scanner (see Fig. 9).

When the digital model for the steel bridge was completed, students proceeded with a visual inspection of the bridge in order to find damage in some elements and then, identify those damaged points in their digital model (Fig. 10).

Fig 8. Guided Experiments on Structural Health Monitoring in both campuses

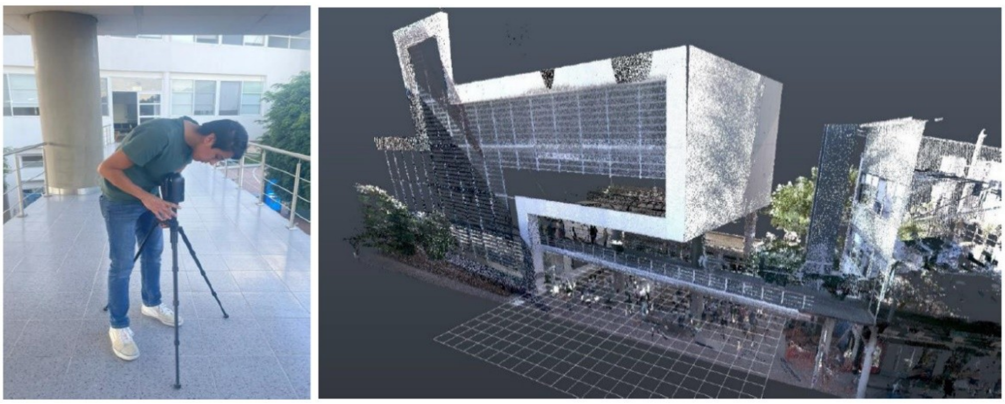

Fig. 9 Digital surveying of the steel bridge using a 3D scanner

Fig. 10 Visual inspection of localized damage in steel bridge

From the visual inspection and localization of damage, students guided by the professors, designed the instrumentation of the bridge, that included: extensometers, accelerometers, inclinometers and strain gauges. The purpose of this instrumentation was to carry out a loading test of the bridge including static loads and dynamic loads for the overall evaluation of the bridge. During this phase, students designed the blueprints for the installation of sensors and performed the preparation and installation of such sensors.

During this challenge phase, students projected on a video wall their measurements with the objective of observing the bridge response under different loading conditions. Since it was in an open campus space, students that were not part of the course approached our students and asked questions about what was happening. This is valuable since this type of activities can be used to attract more students into Architecture or Civil Engineering programs (see Fig. 11).

Once the experiments with measurements on the bridge were finished, students proceeded to calibrate their structural model comparing the observed behavior of the bridge and the instrument readings with the ideal model in a structural analysis software. With all this information, students prepared a digital twin of the steel bridge that allowed them to evaluate different degrading scenarios in time under the assumptions of low maintenance, medium maintenance or adequate maintenance for the bridge.

Fig. 11 Instrumentation and loading tests on the bridge

During the semester, several professors participated of the taught modules, including a visiting professor, that gave lectures on Bridge Engineering to our students. These sessions were taught in English where some recent projects of bridge instrumentation in Europe were shown and how instrumentation and Structural Health Monitoring (SHM) helped some problems in real cases. Professor Milan Sokol visited our campus during this semester to teach a module on Bridge Engineering. Fig. 12 shows his participation.

Fig. 12 Visiting Professor teaching a module on Bridge Engineering

During the last week of the semester, students presented their team projects that were evaluated by a team of professors an researchers of the disciplines related to the concentration diploma. The students presented their solutions to the challenge at the Mexican Institute for Transportation, as our strategic partner (SFP) [8]. The presentations were done by each team in a special visualization lab and while they were presenting, the rest of teams were watching the transmission in real time through Zoom videoconferencing. In this way, all students were able to listen to the feedback for all the other teams. Fig. 13 shows part of the presentation day. Even if Project-based Learning has been widely used in several disciplines [9-21], the approach used for this Concentration Diploma is mainly a Challenge-based model with elements of project-based learning.

Fig. 13 Final presentations at Mexican Institute for Transportation

Students' Perceptions

In order to get some insights into the students' perception of the concentration diploma, students answered a questionnaire covering several aspects of the semester, including the academic aspects and student satisfaction. In this regard, a scale of three levels of satisfaction was chosen for a question: Low satisfaction, Neutral and High Satisfaction with the overall experience. Results shown in Fig. 14 show that 84.6% of students had a highly satisfactory experience with this semester, with 15.4% of students indicating that their experience derived in a semester with low satisfaction or not fulfilling their expectations.

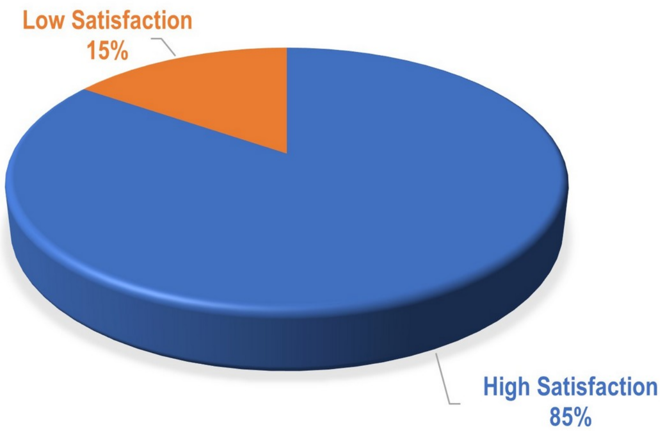

Fig. 14 Students Perception on the level of satisfaction for the overall experience

Another question was about their perception on how the guided experiments and hands-on experience with sensors helped them understand the concepts seen during the class sessions. Using a scale from 1 to 5, where 5 is the maximum value (positive experience) and 1 the lowest value or poor satisfaction with the experimental part. Fig. 15 shows the results where we can appreciate that there were no answers in levels 1 or 2. The majority, 69.23% gave the highest mark, "5", 23.08% gave "4" as their answer and 7.69% with a value of "3".

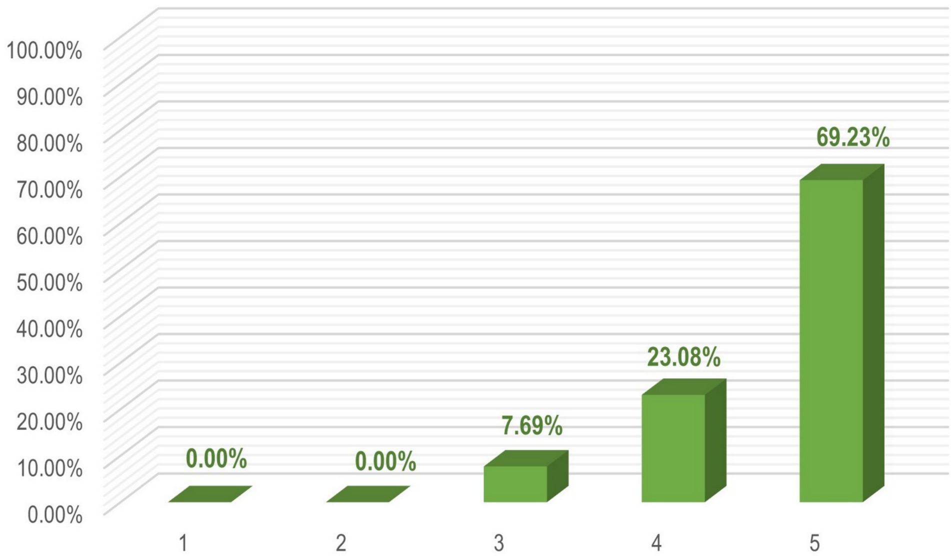

Fig. 15 Level of satisfaction with guided experiments

In the design of this special concentration diploma, a very important component was the application of the theoretical concepts seen in class to a real case scenario. The evaluation of the real steel bridge that is used on a daily basis by students of one of the campus was crucial for the perception of applicability of the concepts. Fig. 16 shows the results. It is important to mention that all answers range from 3 to 5, as there were no answers in levels 1 or 2.

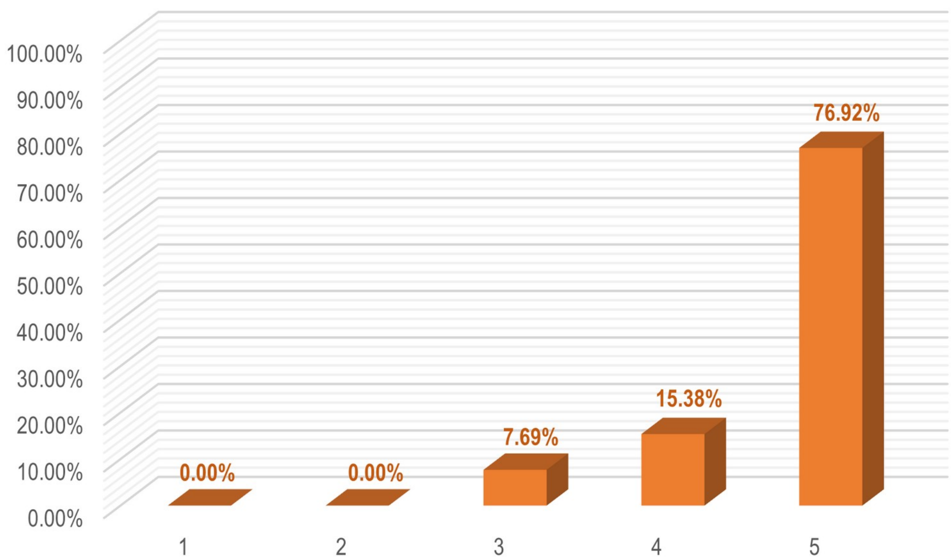

Fig. 16 Level of positive impact of the real bridge in the learning process

When evaluating the impact the Strategic Forming Partner (SFP) had in the learning process and in the solution of the challenge, students answered in the following way, using again a scale from 1 (lowest) to 5 (highest). Fig. 17 shows the perception of students, 76.92% gave the highest mark, 15.38% responded with “4”, and the rest, 7.69% with “3”.

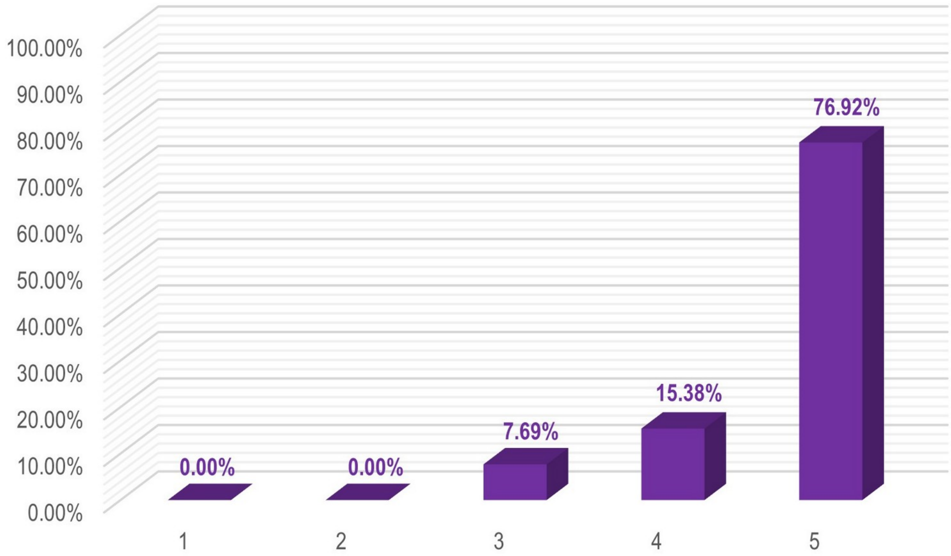

Fig. 17 Students’ Perception on the impact of the strategic forming parner

One question of the survey was about the preferred module among the students, and their answers show that those involving more practical aspects or experiments were chosen as favorite ones by students. Fig. 18 shows their perception, with 46.2% choosing the Module on Structural Loading as their favorite one, Non-destructive tests with 38.5% and 15.4% the Module on Bridge Engineering. The other modules that were not mentioned had no experiments or were seen by students with low applicability.

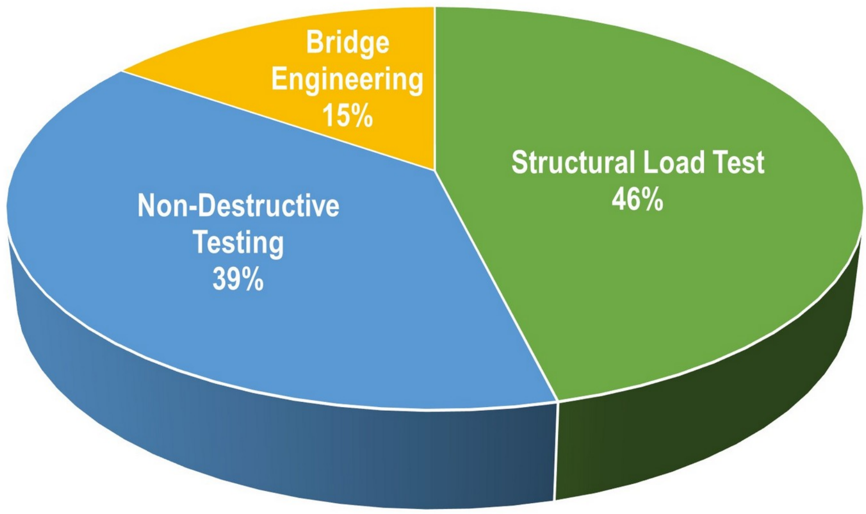

Fig. 18 Preferred modules according to students’ perception

Conclusions

The implemented methodology showed that guided experiments or demonstrations in the lab helped students in their understanding of some theoretical concepts and were preferred by the students to modules in which there were no practical activities in the laboratories. We consider that this experimental work provides a very valuable component to the concentration diploma or minor that the students achieve when successfully completing the semester.

The satisfaction of students was high throughout the semester and it was highest when experiments were performed on the steel bridge of one of the campuses. It is important to mention that his was the first time this Concentration Diploma was offered to our students and therefore, professors were in constant observation of the student satisfaction and feedback.

We consider that this experience will help in future implementations of the Concentration Diploma as we have got very positive comments from students and from the Strategic Forming Partner from Industry, as the diploma covers special topics that are not usually part of a Civil Engineering Program.

Topics such as Structural Health Monitoring (SHM) are becoming more relevant for governments and industry in countries where aging infrastructure needs evaluation and, if needed, structural reinforcement or retrofit.

We present this experience as a successful implementation of a minor or concentration diploma that covers some topics on SHM and it may help other institutions or universities that plan to incorporate such topics in Engineering Programs.

Acknowledgment

The authors would like to acknowledge the financial support of Writing Lab, Institute for the Future of Education, Tecnologico de Monterrey, Mexico, in the production of this work and with funding for attending the 2023 ASEE Annual Conference.

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