ACTIVE LEARNING IN CIVIL ENGINEERING: SOIL-MECHANICS AND STEELWORK DESIGN AS CASE STUDIES

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ABSTRACT

The increasing and rapid technological evolution of digital technology has promoted the embrace of digitalization in the academic teaching of civil engineering. In recent years, new digital technologies have emerged as a real efficiency multiplier for the sector. It's obvious that if we don't adjust our academic syllabus in accordance with this global trend, it will remain obsolete. To circumvent the aforementioned issue, the civil engineering department at Esprit has keenly introduced technologically inclined courses into its academic curriculum by implementing the aspect of digitalization into its engineering program, such as the Soil Mechanics and Design of Steel Framework courses. These courses are taught to third-year engineering students at the ESPRIT School of Engineers. Moreover, to ensure a high level of learning outcomes, several active learning methodologies were adopted (i.e. Flipped Classroom, Project-Based Learning, Peer-to -Peer). The use of previous methods sets students in a better environment in which they can learn efficiently from practicing, develop most in-demand soft skills (such as critical thinking, teamwork, problem solving, time management, creativity, etc.), unleash productivity, and foster innovation and originality. Through this paper, we explain the chosen approaches with extensive details according to the main CDIO standards (like standard 5: Design-Implement Experiences and standard 8: Active Learning), where students are led to gradually use skills acquired during these courses. Such an approach would allow them to acquire advanced design skills while applying their digitization's abilities, for instance, to laboratory soil testing and the development of automated programs to calculate steel framework elements. Finally, we present the main benefits and drawbacks as feedback from applying these new approaches. Nevertheless, we have noticed that when the project consists of solving real-world problems, the commitment and motivation of students considerably increase. Furthermore, this experience provides a rich learning environment and a challenging endeavor.

KEYWORDS

Digitalization of education, Active learning, Soft and engineering skills, Civil engineering, Standards: 5, 8

INTRODUCTION

Digital technology is increasingly invading the engineering profession, and its integration seems almost mandatory in all sectors (Nash, S. et al., 2012). This integration is an obvious result of adapting to the changing needs of society and the market, especially after the COVID-19 pandemic, which forced all sectors to follow this global trend to survive on the market and ensure their share of competitiveness (García-Alberti, M. et al.,2021). The same applies to the construction and civil engineering sectors, which are making great strides towards the integration of digital technology, with an average annual growth rate of 16% by 2025, according to a study by Roland Berger (2023). This estimated strong growth is due to the advantages of digitizing civil engineering, with gains that can be estimated at $1.6 trillion per year worldwide. According to a McKinsey study made by Koeleman, J. et al. (2019), the gains from digitalization are derived from the benefits of integrating digital technologies, such as customization of projects, reduction of costs and deadlines, improvement of quality and safety, sustainability and environmental responsibility, etc. And to succeed in this challenge of digital transformation, the civil engineer as well as one of the actors must also align digitalization through the acquisition of new skills that adapt the most commonly used digital technologies, such as BIM, IOT, etc. The training of civil engineers plays a key role in the acquisition and development of digital skills for the future, which must be based on the adaptation of content and methods of educational tools to digital technologies. This is why the civil engineering department has begun to integrate these new technologies into the training of engineers. This paper develops our experience with 3-year engineering cycle students in the reform of both foundation and support modules and steel framing. In the first two sections, let us detail our framework for the two modules. The third section will deal with the limits, and we will end with a conclusion.

METHODOLOGY

The way we teach is continuously changing. With the emergence of new teaching approaches, we are witnessing a paradigm shift from classic to active learning (Asok, D. et al., 2019). We sometimes call it the facilitation of learning. With the development of technology, students find themselves in front of an abundance of information available almost instantaneously. They don’t need the physical companionship of the teacher to advance in their learning, at least from those who are autonomous. Hence, educators must play a different role than the traditional one, where they act as facilitators and teach students how to learn effectively, discover, and filter relevant information rather than being transmitters of information.

The literature describes a variety of educational research approaches, including experimental, survey, and action strategies. The effectiveness and quality of their results vary depending on the phenomenon under investigation or the problem being treated. The choice of methodology is critical since it drives the study plan and defines data gathering and analysis scheme. The current study primarily used the action research methodology, which was deemed more appropriate and efficient for achieving our overall goal of improving the educational technique currently used at ESPRIT, School of Engineering, through promoting self-directed learning, autonomy, and project design skills among engineering apprentices. Action research typically seeks to improve the current situation rather than to generate generalizable theoretical knowledge. As a result, such strategies commonly lack extensive documentation and formal reporting. In this paper, the action research strategy was based on four pillars: a. literature studies and results from similar projects, b. instructor observations based on their prior experience teaching the concerned courses, c. our personal involvement in improving the courses concerned by the current study at the ESPRIT's civil engineering department, and d. feedback from students who have participated in the courses under study.

As expected, a relevant similarity has been perceived between the observations reported in the literature (Chia Chew Lin et al., 2020) and those revealed by the instructors of the courses. According to teaching staff observations, a large percentage of students consistently show a strong inclination to ask their lecturers to give them direct answers on a one-on-one basis, demand instructors correct their mistakes, or display anxiety and resistance to develop their numerical and experimental tools to tackle the theoretical problem or invent or improve an approach or apparatus to measure physical parameters by using technological, coding, or designing skills. While the teaching staff has to guide them with considerable effort. Implying that quite a number of the students are not ready or simply reluctant to take ownership of their learning or challenge themselves to acquire new skills beyond their field of expertise. Still, it was also observed that some students are very driven, self-directed, enthusiastic about experimenting, and self-learning new abilities. By referring to Gibbon's Spectrum of Self-Directed Learning depicted in Figure 1., our students can be identified at different levels, with quite a handful of them falling into the self-directed learning phases while the majority of them have exhibited behaviors that indicate low ownership or considered as incidental self-directed learner as per the definition of Gibbon (2022).

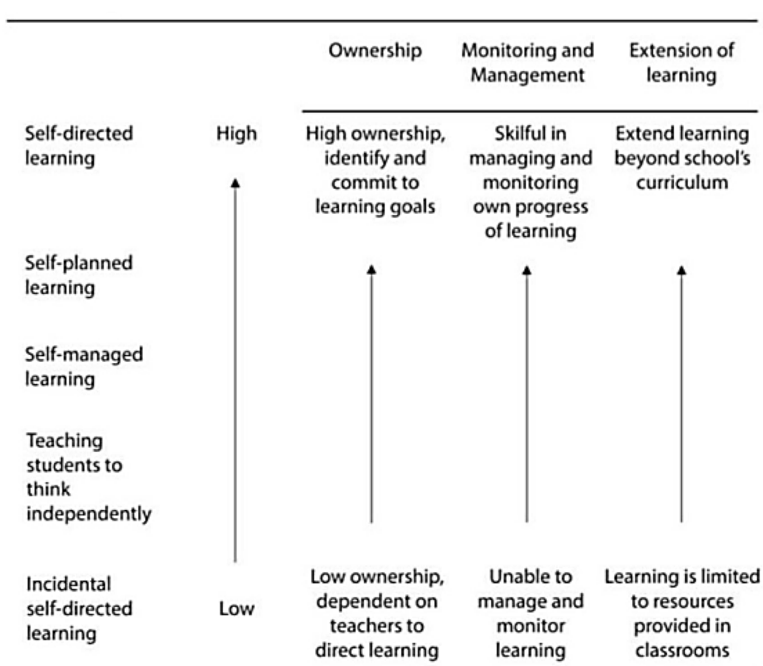


Figure 1. Gibbons Spectrum of Self-Directed Learning

To achieve this study objectives, a feedforward method has been adopted where interventions have been implemented in both courses to encourage students to become self-directed learner while acquiring new coding, design and research skills. Changes carried out for the courses are explained with further details in subsequent sections of this paper. At the end of the courses, surveys to evaluate the new versions of courses with recommended changes have been distributed to students. Hence, results of the surveys have been analyzed in order to confirm success of the experiment and interpret a further change that may improve other aspects of the courses that were not improved by the modifications adopted during the current version of the courses.

Design of steel framework course

In this context, and as a traditional continuous improvement adopted by the civil engineering department, I decided, two years ago, to switch the pedagogical way of teaching the “steel framework design” course from an almost classic paradigm to a multi-active approach to learning where students are considered the central part of the teaching process. The course of “steel framework design” forms part of the civil engineering undergraduate program and is one of three modules offered in steel design. It is a lecture-based course and consists of a series of eight chapters. Students learn about the fundamentals of designing steel elements (like beams and columns, etc.). The design and calculations of real elements (such as portals, beam columns, purlins, paddings, connections, etc.) are covered in the second semester simultaneously with the laboratory software. In order to achieve all the desired learning outcomes, students must not only possess strong prerequisites but also develop the most in-demand engineering and soft skills. In a nutshell, let us define the scope of the arrangement and the material of the course. It is comprised of eight chapters, organized as shown below in Table 1.

Table 1. Content of the 42-hour “Design of Steel Framework” course

Chapter #	Name	Duration
1	History, Introduction, fields of application and terminology of steel construction	4 hours
2	Basis design of steel construction design according to Eurocodes	2 hours
3	Calculation of climatic loads (wind and snow) on constructions	6 hours
4	The essence of the resistance design of steel members without consideration of buckling effects	10:30 hours
5	Justification of compressed elements considering buckling effects	4 hours
6	Justification of bent elements with respect to lateral torsional buckling	6 hours
7	Justification of elements with respect to local buckling	3:30 hours
8	Design of composite slabs and Beams	6 hours

Besides, these are the principal learning outcomes of the module:

- recognize structural steel fabrication processes;
- memorize the terminology of a hall-type steel structure;
- calculate the wind action on a quadrangular steel construction;
- justify the metal parts regarding the stresses applied, considering the phenomena related to shape instability (buckling);
- use and apply standards for the design of structural steel and composite elements.

In the traditional way, the instructor first exposes the principals and concepts covered by the course using a data show and whiteboard, followed by a resolution of a series of exercises. Usually, some students apply. They participate, share their ideas, ask questions, do calculations, and take notes, while the majority is inactive, and in the best case, those students are limited to just following up on the correction. The rhythm is so tensioned and stressful. Therefore, the post-exams evaluation shows a very weak rate of learning outcomes and is almost inefficient and unacceptable. In its newest form, students are organized into groups of three individuals. Then, the content of the course is assigned to each group, and the material pertaining to every chapter is allocated to each member of the group. Here, we recall the flipped or inverted classroom, team-based learning, and peer-to-peer learning methodologies. Figure 2 illustrates the arrangement of groups in a typical classroom, the relationships between members of each group, and the eventual relationships among every group and other groups (showed in red arrows). We can see that the acquisition of related learning outcomes is constructed not only by personal effort but is substantially based on interactions between all members of a group and even with other members of other groups. This involves students working together in a personalized learning environment and supporting each other in the learning process without the need for direct and recurrent teacher's support. They feel more involved, applied and motivated in the teaching process.

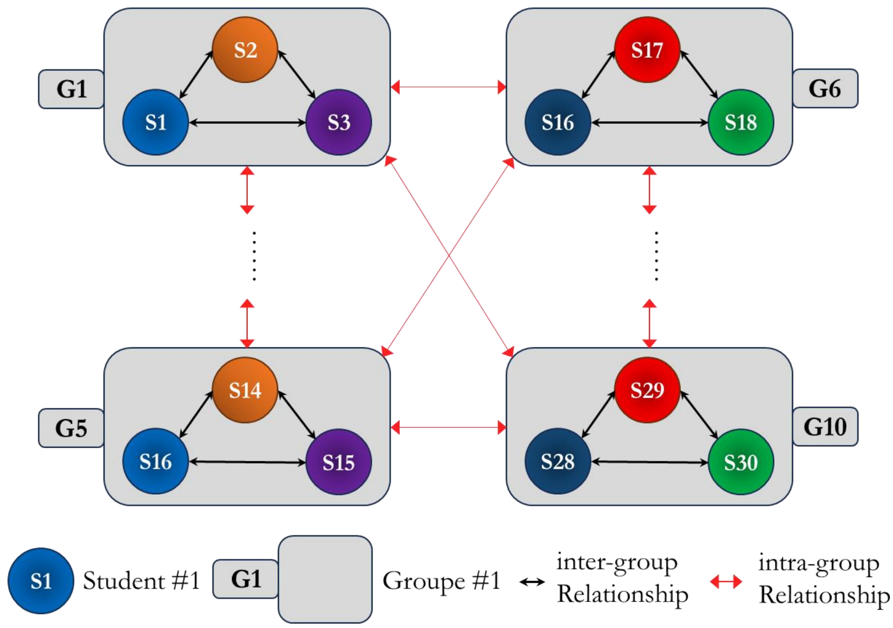


Figure 2. Illustration of the arrangement of groups in the classroom

At the beginning of each chapter, the instructor provides and exposes the principal concepts of the course. Then, each learner has to read and understand it attentively at home and in person, consult related parts of the Eurocode, try to induct a recap, and then implement the different exercises on MS Excel spreadsheets. To do so, students have to toggle between course material, some books, MS Excel tutorials, online resources, and last but not least, Eurocodes. It is important to be patient, autonomous, and careful to grasp only relevant information in order to create links between ideas, understand the concepts in depth, and learn how to be more effective and concise in filtering only the necessary information from available data. The instructor, as mentioned above, plays the role of a tutor or coach that facilitates and encourages conversations and teamwork collaboration. He also guides them towards the right choices without disclosing explicitly the solution as it was in the traditional way. Once the work is done, so that each student in all groups has effectively accomplished his part of the work, he should then explain what he has learned and accomplished to his groupmates, since for each chapter, every student has almost one-third of the content. As a practical example, we take the fourth chapter that deals with resistance design. But before starting calculations, some preparations must be made. Hence, in the first part, the first student is charged to learn about section class principles and how to determine the type of analysis according to Eurocode3. The second student is engaged in calculating section geometrical and mechanical characteristics, and the third one is expected to conduct a Von Mises section assessment. Those concepts are essential to conducting resistance design, which is covered in the second part of the chapter.

Soil mechanics rocks course

mechanics plays a crucial role in the training of engineering students as it provides them with both theoretical and practical knowledge to design, construct, and control various geotechnical structures such as foundations, retaining walls, dams, tunnels, embankments, and dikes. It can also be used to predict the behavior of soils under the effects of geotechnical loads. In the civil engineering department, soil mechanics is spread over two semesters. In the first semester, students follow a theoretical module in soil mechanics and do practical work in the soil mechanics laboratory. In the second semester, students follow another theoretical module called foundation and support and another module in the form of a project called "BE Foundation System," which aims to design and calculate underground and surface structures. Recently, a reform has been carried out over the last two years on the foundation and support modules, with an hourly load of 42 hours. The reform essentially concerns the integration of a part in the course called TP-Design of Geotechnical Characterization Tools in the form of an APP where the student is called to: a. Study and design test apparatus and b. develop digital tools (e.g., programming or coding). In summary, the implementation of this reform will provide students with valuable digital knowledge and practical skills in geotechnical engineering, ultimately enhancing their future career prospects.

Project selection

At the beginning of the semester, the project is launched to the student, detailing the pedagogical objective and the outcomes of the module already mentioned. The start-up always begins with the presentation of the problem, which has been the improvement of the existing geotechnical test strips in the Soil Mechanics Laboratory or the design and implementation of new tests that can be useful by integrating the numerical parameter.

Table 2. List of Soil Mechanics Projects

#	**Title of the project**	**# Groups**
1	Variable and constant load permeameter with measuring sensor	2 groups
2	oedometer test	1 group
3	Permeability-meter and soil moisture sensor	1 group
4	Casagrande Test Modeling	1 group

The choice of project is based on a bibliographic study and the students' feedback on the "Soil Mechanics Practical Course", and this is done with a view that aims to boost their creativity and involve them in the learning process by developing their critical sense and their skills in bibliographic research and group work. After two weeks of desk research and testing the needs of the soil mechanics laboratory, each group presented their project idea in front of their classmates, and a working session was scheduled to discuss and validate the project idea. Table 2 illustrates the projects proposed and implemented by the students.

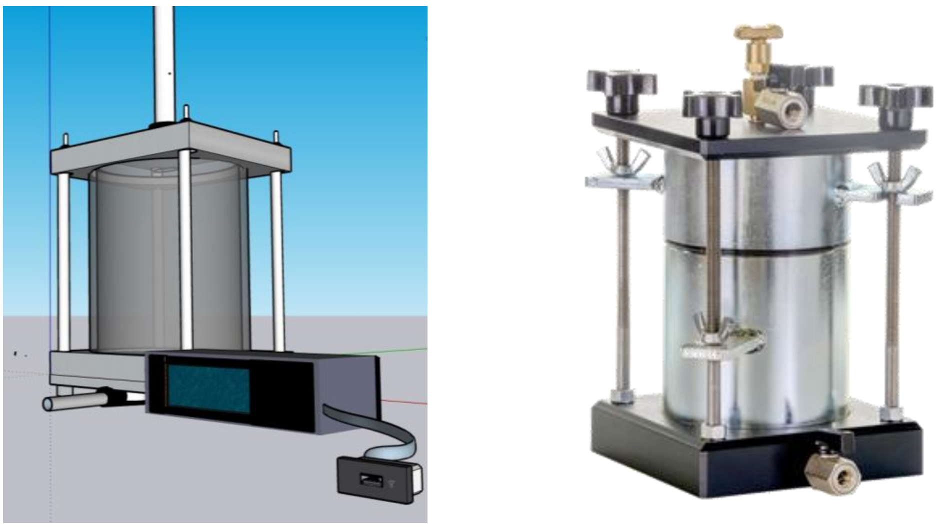
Results and implications

The ever-moving reality in the world implied a major change to the engineer profile. Hence, proper education, which means equipping the engineering students with proper technical and interpersonal skills, raises as a necessity, allowing them to lead the changes required worldwide. Limiting the apprentices of engineering to technical skills, such as repetitive calculations and deploying empirical correlations, is deemed insufficient to meet the needs of their projects. Engineers need to develop their own tools for simulation and build their own experimental setups that satisfy the requirements of their projects or innovative ideas. Innovation requires thinking outside the box and eventually using different tools besides those that are available.

In accordance with the aforementioned objectives, the engineering apprentices in their third year of civil engineering have been challenged with real-world problems related to geotechnical fields. Most of the equipment that is in the school laboratory is still classic, fully relying on the human being, involving several repetitive and time-consuming tasks. Permeability measurements and oedometer testing are among the most common techniques that are required by civil engineering projects and have hence been selected from the list of projects presented in Table 2. The students were required to optimize the previous tests by automating the process involved. Three teams were established to conduct the project: the first team is responsible for the numerical modeling of the permeability meter, the second team is responsible for conducting electronics wiring and data acquisition systems, and the third team is responsible for building the equipment (Figure 3). The objective was to establish equipment that allows the automatic measurement of a soil sample during transient and continuous flow regimes. Thus, the Darcy equation was reached by implementing the differential pressures and flow rates that are continuously determined using the sensors installed on the permeability-meter equipment. Consistent communication between the three teams has been established throughout the project period in order to ensure a fluid exchange of information between them. The project was considered challenging at several levels, as inferring learning unconventional skills for a civil engineering apprentice: computer-assisted design (CAD), electronics wiring and programming, and constructing a full-edged electrometrical system that was tailored in accordance with the specific needs of the school laboratory, in addition to enhancing interpersonal skills like technical reporting, professional communications, leadership, and teamwork capabilities.

For the oedometer, the classic approach requires a manual measurement at a specific time frame that can range up to hours and even days. To overcome previous time restrictions and reduce the human error involved during the recording of measurement processes, the team members have designed an electronic data acquisition system allowing a systematic recording of the subsidence during the evolution of the oedometer tests. The experimental data acquired is hence interpreted, and soil parameters are inferred automatically by the software programmed by the students (Figure 4). The previous learning-through-project approach has promoted the professional and interpersonal skills of apprentices in the civil engineering departments, allowing them to acquire transferable acquaintances and capabilities that can apply to real projects during their professional careers afterward. The challenging realities of the engineering world today indicate that graduate engineers go beyond and beyond classic knowledge to extend covering, programming, design, and custom to find solutions to the “not-regular” problems that they may face during their career.
The results of surveys, Figure 5; depicted a high satisfaction by the students in regards to the new learning approaches adopted for the course. The strategy to use less direct instruction to promote active learning in the classroom was a helpful and well appreciated by the apprentices

so it will remain for the next year. Still, learning coding, technological (electronics programming and installation), and practical research skills represented a major challenge to the students who felt overwhelmed by the extent of knowledge and prerequisite that need to be acquire in a short period. To deal with the previous issues; learning strategies, including teaching the students the right mindset to conduct research work; as well as organizing short training sessions in coding and electronics programming, have to be planned for the next academic year.



a. b.

Figure 3. Permeability-meter: a. CAD and b. Prototype

```
# -*- coding: utf-8 -*-
"""
Spyder Editor

This is a temporary script file.
"""

import serial
import matplotlib.pyplot as plt

# Configure the serial port
-ser = serial.Serial('COM3', 9600)

# Set up the plot
plt.ion()
fig, ax = plt.subplots()
line, = ax.plot([], [])

# Initialize the data arrays
x_data = []
y_data = []

# Start the plot loop
while True:
    # Read a line of data from the serial port
    data = ser.readline().decode().split(",")

    print(data)
```

```
    # Convert the data to a float and append it
to the arrays
    try:
        time = float(data[0])
        value = float(data[1])
        x_data.append(time)
        y_data.append(value)
        print(time)
        print(value)
    except:
        print("error")

    # Update the plot
    line.set_xdata(x_data)
    line.set_ydata(y_data)
    ax.relim()
    ax.autoscale_view()
    fig.canvas.draw()
    fig.canvas.flush_events()
```

Figure 4. Oedeometer: data logging code snippet

CONCLUSION

In recent years, companies have tended to adopt a skill-based hiring approach based on candidates' holistic set of skills and not just their educational qualifications. Thus, we can say that these emerging methodologies contributed to responding to this need and helped to create a friendly atmosphere and suitable environment where students could develop and foster their skills and learn at their own pace instead of staying passive and wasting time. Furthermore, this allowed students to:

- be more autonomous and self-confident,
- share their thoughts and perspectives and exchange ideas.
- recognize the utility of active learning and be cautious about the necessity of digitalization.
- learn in a personalized and more flexible learning environment.
- collaborate and resolve conflicts and disagreements;
- feel more involved, applied and motivated in the teaching process;
- develop personal skills, etc.

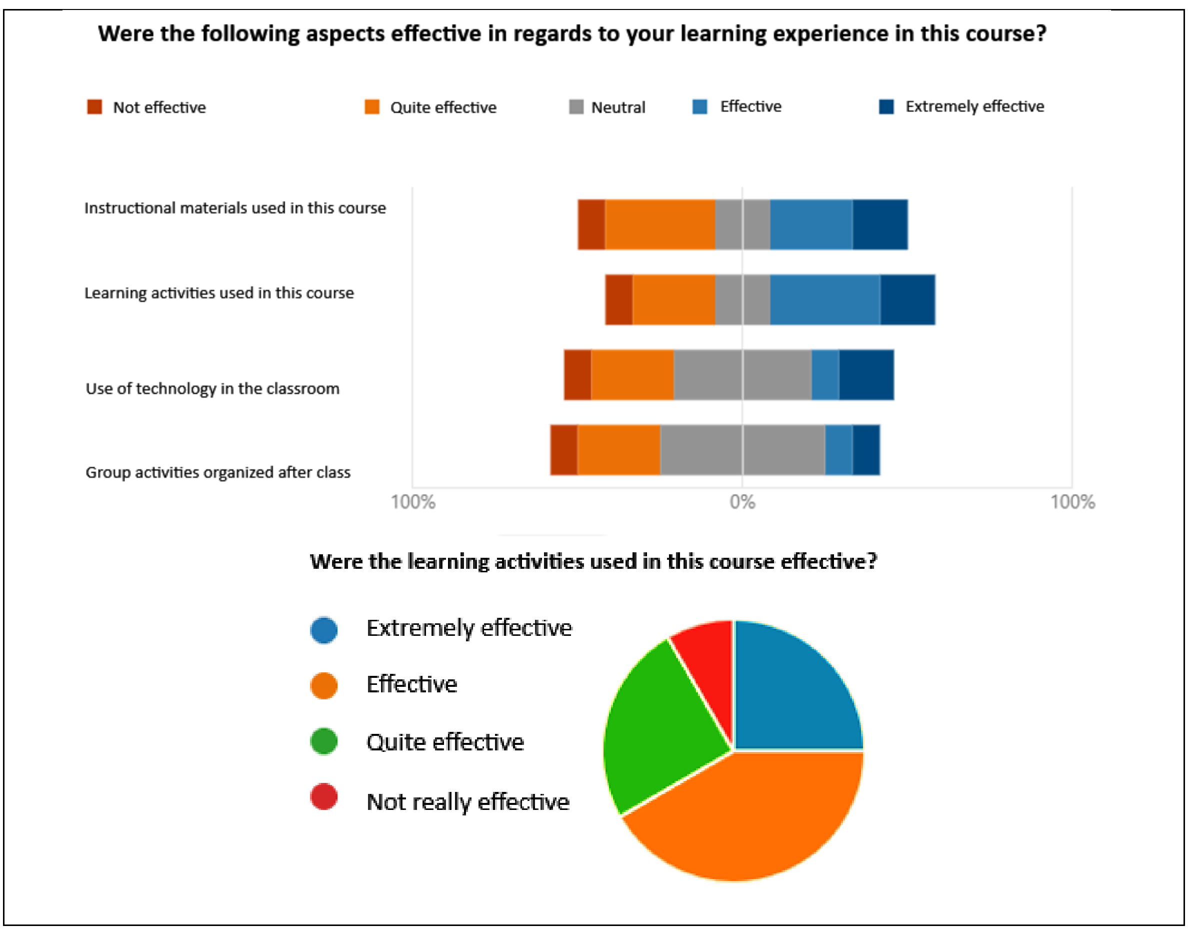


Figure 5. Surveys results

Moreover, digitalization enables engineering education to be more innovative, collaborative, and efficient. It contributes to enhancing the quality of education and accessibility to curricula. Future engineers, by automating tasks using software tools, will:

- perceive things differently and from wider perspectives;
- develop high-demand 5 C's competencies: collaboration, communication, critical thinking, creativity, and choice;
- save time and become more efficient in problem solving;
- improve problem-solving and time-management skills;
- became more capable of handling advanced and more complex problems.

However, the results of some methodologies remain controversial as students may differ on their level of understanding and be inclined to use other students' thoughts and reproduce them in their own assignments (Zhang, A., 2012). Generally, the method of using less direct instruction to foster active learning and promote designing capabilities was effective and well recognized by both the instructors and the students. However, acquiring advanced coding and technological skills presented a significant obstacle for the students. Therefore, it is recommended to organize short coding and electronics programming training sessions prior to or at the start of the courses. Finally, we hope that this work will inspire our colleagues to start considering the learning approaches investigated and implemented in this study for their own courses as promising impacts are highly anticipated based on results obtained in this paper.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

The authors did not receive support from any organization for the submitted work. No funding was received to assist with the preparation of this manuscript. No funding was received for conducting this study.

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BIOGRAPHICAL INFORMATION

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