Virtual Globalization: An Experience for Engineering Students in the Education 4.0 Framework

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Abstract

In February 2020 the World Economic Forum published its report on the characteristics of Education in the Fourth Industrial Revolution, of which several stand out for their relevant impact on engineering programs. These are: (i) Global citizenship, building awareness about the wider world and playing an active role in the global community; (ii) Collaborative learning, requiring peer collaboration and a move to project- and problem-based content that more closely mirrors their future work; (iii) Innovation and creativity skills, including complex problem-solving and analytical thinking.

In March 2020, the emergence of COVID-19 forced educational institutions to abruptly adopt social distancing and quarantine measures, making compliance with the Education Framework 4.0 much more challenging. However, these challenges led to new opportunities. Lecturers from two universities (separated by 9,500 km and 7 time zones) were discussing for some time, how to make it possible to give students the opportunity to live an international experience within the Education 4.0 Framework. The result was a project of international cooperation, negotiation, leadership, empathy with a broad perspective. The main questions that guided the foundations of this cooperation project were related to the specific problems that engineering schools had to face during the COVID-19 crisis: How to meet the special requirements of courses with a Challenge-Based Learning approach? How to carry out the laboratory practices -normally included in some courses- in a collaborative remote learning way? How to compensate for the cancellation of the international exchange of students enrolled in engineering programs?

The presented study includes: (i) The methodology used for the selection of subjects in which cooperation was established; (ii) The collaboration plan of the lecturers involved; (iii) The design of the experiences for the realization of remote practices "hands on" (via VPN); (iv) The selection of the technological platforms that would best be adapted for the collaboration and exchange of material; (v) A description of how the didactic techniques and spaces for interaction were chosen at different levels (student-student, student-teacher and teacher-teacher).

Finally, a brief summary of the preliminary results of the impact measurement is included, with the opinion surveys of the students and the grades obtained in the courses. This study is of special interest to the Cooperative and Experiential Education Division (CEED) of the ASEE since it is focused on improving and promoting experiential learning through cooperative education and virtual internships.

Keywords: Higher education, Educational innovation, Active learning, Challenge-based learning, International cooperation.


Introduction

In their latest reports, both, the Organization for Economic Co-operation and Development, OECD, and the World Economic Forum, WEF, introduced a comparison of today’s skills with those demanded of future professionals, to face the challenges of the Fourth Industrial Revolution [1][2]. Table 1 shows the skills expected to be trending by 2022: Innovation, Active Learning and Creativity are on the rise.

<table>
<thead>
<tr>
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<th>Increasing skill demand by 2022</th>
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<tbody>
<tr>
<td>1</td>
<td>Analytical thinking and innovation</td>
</tr>
<tr>
<td>2</td>
<td>Active learning and learning strategies</td>
</tr>
<tr>
<td>3</td>
<td>Creativity, originality, and initiative</td>
</tr>
<tr>
<td>4</td>
<td>Technology design and programming</td>
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<tr>
<td>5</td>
<td>Critical thinking and analysis</td>
</tr>
<tr>
<td>6</td>
<td>Complex problem-solving</td>
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<tr>
<td>7</td>
<td>Leadership and social influence</td>
</tr>
<tr>
<td>8</td>
<td>Emotional intelligence</td>
</tr>
<tr>
<td>9</td>
<td>Reasoning, problem-solving and ideation</td>
</tr>
<tr>
<td>10</td>
<td>System analysis and evaluation</td>
</tr>
</tbody>
</table>

Several researches in the literature review addressed the issue of how to develop those and even other skills by incorporating multiple technological tools [3]. Some of the most common implementations are: gamification, incorporation of online applications, use of smart devices for communication and delivery of tasks; use of augmented & virtual reality programs; internet of things and other innovative tools [4]. These implementations are especially noticeable in STEM (Science, Technology, Engineering, Mathematics) programs, which are the ideal environment to use all technological implementations as tools in the teaching-learning process [5] [6].

In addition, higher education in the Fourth Industrial Revolution can be identified with four skills and four learning characteristics of high-quality learning of the Education 4.0 Framework [7] as shown in Table 2.

<table>
<thead>
<tr>
<th>Skills</th>
<th>Learning Characteristics</th>
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<tr>
<td>Global citizenship</td>
<td>Personalized and self-paced</td>
</tr>
<tr>
<td>Innovation and creativity</td>
<td>Accessible and inclusive</td>
</tr>
<tr>
<td>Use of Technology</td>
<td>Collaborative</td>
</tr>
<tr>
<td>Interpersonal Intelligence</td>
<td>Student-driven</td>
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While the COVID-19 crisis has put the world on hold, new ways had to be found to make life, and education go on regardless. All university programs including engineering education changed physical classes with virtual teaching. Although this was a good emergency solution, the students still needed to get used to this situation, which was not easy for all [8][9]. However, these challenges also gave way to new opportunities. Lecturers from Tecnologico de Monterrey, TEC, in Mexico and the Technical University of Denmark, DTU, started discussions on how to maintain international collaboration in engineering educational programs in this new situation, where the exchange of students and lecturers will not possible for some time into the future. Most engineering programs include several possibilities to train students with international skills [10][11]. Globalization and international skills are required in many industrial companies and universities are recommended to train students to work in teams with students in other countries [12][13][14]. In this scenario, Covid-19 restrictions gave us new opportunities for virtual training of students to obtain international skills, and at the same time without the need to find funding for international travel and accommodation cost.

There are many ways to collaborate and take advantage of the opportunities that the virtual model offers us to give a global view to students. For this, programs such as Global Classroom agreements with universities and other types of collaborative programs have been launched using remote classrooms and laboratories. This paper presents a study of how the intervention of the expertise of foreign lecturers in virtual classes positively affected students and added value to the courses they were enrolled in.

**Theoretical Framework**

It is particularly significant that recent studies of higher education emphasize the need for instructors and students to develop a wide range of cognitive, social and emotional competencies, called 21st Century Skills [15]. These skills make up a modern form of literacy, digital literacy, which is critical for training, learning, upskilling and reskilling with digital technologies in today's virtual education environments.

Education 4.0 is changing the way today's young students will live, work and interact during their careers in the future, therefore, technological advances should act as enablers in the reinterpretation of cognitive theories and teaching techniques for the development of criticality. Our challenge as educators is how to employ innovative, virtual and technological tools that boost creativity and challenge students to solve complex problems using unexpected solutions; appealing to the extensive use of their digital literacy skills [16]: Photo-visual; Reproduction; Branching; Information; Socio-emotional; and Real-time.

The incorporation of reflective practices through spaces for dialogue in fully online environments should be carried out throughout the engineering program as an example of cognitive and metacognitive tools using the technological platforms that are best adapted to each subject. The objective of this approach favors the establishment of a common language (written, oral, digital and visual) and develops, on the one hand, the skills declared in the Education 4.0 framework, and on the other hand, the skills of digital literacy required by current workplaces. Recent studies, related to the establishment of safe and healthy socio-emotional environments in virtual environments, show the great importance that the dispositions inherent to interpersonal awareness represent (shown in Table 3) for the
implementation of the active learning approach. During 2020, and due to the COVID-19 crisis, the analysis of these provisions has been resumed, but adapting them to remote and virtual education environments.

Table 3. Interpersonal soft skills for enhance metacognitive awareness in virtual environments

<table>
<thead>
<tr>
<th>Soft Skill</th>
<th>Inherent disposition</th>
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<tbody>
<tr>
<td>Self-motivation</td>
<td>To be able to motivate oneself without the need of external influence factors.</td>
</tr>
<tr>
<td>Self-awareness</td>
<td>Be responsible for your own thoughts and behaviors.</td>
</tr>
<tr>
<td>Communication</td>
<td>Communicate effectively with active listening and constructive feedback.</td>
</tr>
<tr>
<td>Collaboration</td>
<td>The ability of an effective interaction work.</td>
</tr>
<tr>
<td>Perspective taking</td>
<td>Being able to understand different points of view with which you do not agree, without letting the disagreement interfere with one's reasoning.</td>
</tr>
<tr>
<td>Understanding of diversity</td>
<td>Consider the integration of gender, nationality, beliefs and experience.</td>
</tr>
<tr>
<td>Ethics</td>
<td>Be able to face ethical dilemmas in the professional field.</td>
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Collaboration Setup and Timeline

With the theoretical framework of Education 4.0 in mind, collaboration between both institutions was initiated in March 2019 to establish a common ideas and interests framework. The ASEE 2019 conference presented the ideal opportunity to meet in-person for drafting of more detailed definitions for suitable projects with engineering students from both institutions. It was not until March 2020, and due to the beginning of the state of contingency due to COVID-19, that the idea of virtual collaboration arose and a more formal collaboration and meeting agenda was established that culminates with the interventions of the Danish lecturers in two courses taught by Mexican lecturers, in the Fall 2020 and Spring 2021 semesters, as shown in Figure 1. The figure provides some details of the meetings (in person and online that were held; the international conferences in which the authors gathered and a list of activities that were carried out before the interventions with students. Details about the participants, instruments and measurements are explained in the Methodology section.
The detailed schedule for the presentation of the interventions to the students of both courses was as follows:

- **Second week of classes.** The joint presentation of the lecturers from both universities was made, and the different topics of collaboration were established. The lecturers share the course schedule and the content of the interventions in the corresponding syllables.

- **Third week of classes.** Each pair of lecturers (Mexican and Danish) have separate meetings to discuss the logistical details of each intervention, taking into account the results of the interest surveys answered by the students in each group.

- **Fourth week of classes.** The details of the first intervention are established taking into account the updates made from the diagnostic evaluations and the PreTests.

- **Fifth week of classes (September 2020 for the Fall semester and March 2021 for the Spring 2021 semester).** The first intervention was carried out in both groups. Incidents and comments were recorded in meeting logs.

- **Sixth week of classes.** The four lecturers meet for a feedback session, discuss the comments made in the perception survey answered by the students after the first intervention, and design the second intervention.

- **Seventh week of classes.** The details of the second intervention are established taking into account the updates made from the opinion polls.

- **Eighth week of classes.** The second intervention was carried out in both groups. Incidents and comments were recorded in meeting logs.

- **Ninth week of classes.** The four lecturers meet for a feedback session, discuss the comments made in the perception survey answered by the students after the interventions and establish the strategy to continue the project in future semesters.
Methodology

Participants. A total of 47 undergraduate students of engineering programs have participated in this program. Participants joined the study voluntarily, with an average age of 22 years, all of them considered to belong to generation Z (born after January 1, 1995) [17]. The study was deploying over the fall semester, from August 2020 to November 2020. Students were distributed in two courses of the B.S. Sustainable Development Engineering program and the B.S Mechatronics Engineering program (the official ID of each course appears in parentheses) taught by the Mexican lecturer, as follows: Technologies for the Energy Distribution Systems (TE3053) and Computerized Control (MR2007).

Instrumentation. Diverse types of instruments were used: diagnostic tests, with multiple-choice and true or false questions designed to establish the approximate knowledge of each student; questionnaires, to understand motivation and intellectual engagement; exit surveys, to determine student satisfaction; and finally, to assess how well students performed each outcome and considering that assessing the evidence for skills typically involves subjective judgments concerning products or behaviors, an already-existing rubric was used, the VALUE Rubrics, from AAC&U, developed for the Essential Learning Outcomes of the Association of American Colleges and Universities [18].

Procedure. Some of the essential conditions to promote effective Active Learning, AL, and Challenge-based Learning, CBL, experiences in the virtual experiences of the study were [19][20]:

• Learning experiences should include activities of reflection, critical analysis and synthesis.
• Learning experiences should be structured in a way that promotes decision making and student responsibility for results.
• Students must participate actively and creatively in the approach and solution of the problem.
• The experience must involve all participants not only intellectually but also emotionally and socially.
• The instructor and students may experience success, failure, uncertainty, and risk taking, because the results of the experience may not be entirely predictable.
• The instructor recognizes and promotes spontaneous learning opportunities.
• The instructor has among its functions the declaration of the problem, the establishment of limits, facilitating the learning process, supporting the students, as well as ensuring the physical and emotional integrity of the students.
• The learning outcomes are personal and are the foundation of future experience and learning.
• The experience should promote students' self-awareness, empathy with their peers and a greater knowledge of the environment and other cultures.

AL and CBL are approaches of andragogy that has been successfully incorporated into engineering curricula because it achieves a real-world perspective and considers student learning to be "doing" about a topic of study. These approaches offer a student-centered learning framework that emulates real work experiences in industry and corporations: they build on student interest in giving practical meaning to education, while developing key competencies observed by organizations international: Leadership and social influence;
Emotional intelligence; Reasoning, problem solving and ideation; and Analysis and evaluation of the system.

The process of involving interventions by external -Danish- lecturers to a course was carried out always favoring the generation of safe and trustworthy spaces. This type of intervention required a very close collaboration on the part of the instructors (hosts and guests), who met in the previous months to define the scope and plan the topics and dates of each intervention. Some of the actions involved were:

1. Identify topics and content based on diagnostic tests
2. Implement a joint work plan with dates of interventions.
3. Design the activities of the AL and CBL approaches
4. Carry out the intervention in class, along with the material and activities designed.
5. Analyze findings and provide feedback on student performance
6. Collect the opinion of the students through exit surveys.
7. Manage an improvement plan for future interventions.

Experimental Settings

*Experience in Computerized Control (MR2007)*. The 20 students and the Mexican professor participated in online classes using the Zoom© platform. Two interventions by the Danish lecturer were planned to allow the correct development of the topics and the simulations. To exemplify the activities and explain the related phenomena, Matlab© and Simulink© were used as support tools. The general objective of the course was the design of controllers that can be implemented in digital devices, such as microcontrollers, computers, PLCs and any other programmable digital device. That is why there were concepts -from the selection of the sampling periods and the discrete representation of the model to be studied- that implied the study, design and implementation of digital controllers. This type of application includes practical aspects for the implementation of the system, such as: physical limitations of the components, differences between the theoretical model and the real model, and ease of programming the controller. It is important to note that two previous meetings were held between Mexican and Danish lecturers to ensure the logistics of the interventions and adequate timing.

The first intervention aimed to reinforce the knowledge acquired in system digitization and controller design, while the second focused on how to compensate for some physical limitations in the implementation of controllers. Lecturers from Mexico and Denmark first worked on identifying two of the course topics that would be suitable for invited lectures, considering the level of the course and the results of diagnostic tests of the Mexican students. These classes belonged to the traditional program but, with the interventions, allowed the students a new approach to the subjects. The Danish lecturers had extensive industrial experience, and therefore our choice was to focus on the practical application of the theory with simulations illustrating the topic. The students received the introduction of each topic with their own lecturer and all the materials were available in advance when the lecturer from Denmark made the interventions in the classes. In Figure 2 is shown a frame collection of different instances of the experience.
Lecture #1:
- General introduction: presentation of the Danish university and lecturer.
- Ziegler-Nichols tuning methods.
- Discretization of the controllers using Matlab©
- Working with problems

Lecture #2:
- Introduction to PI-controller
- Saturation of PI-controllers, illustration of the effects of saturation in industrial applications
- Tuning of PID-controllers with Matlab© and Simulink©
- Working with problems

Experience in Energy Distribution Systems (TE3053). The experience of management and monitoring of electrical energy efficiency in smart microgrids was carried out during the 2020 fall semester, in collaboration with an expert instructor, a lecturer from a Danish university. The 27 students carried out the activity, which was divided into four stages: 1) Theoretical training and training, 2) “hands-on” remote laboratory, 3) Work sessions, 4) Final presentation. This CBL project placed students in direct contact with industry and utilities to address the energy needs of a real customer, allowing them to become familiar with concepts and activities that would be relegated to the secondary plane, if not entirely omitted in a traditional teaching environment. These activities include the delivery of preliminary energy diagnoses, the recognition of industrial equipment in real electrical installations and the analysis of data for energy efficiency, which involve preliminary correlations with variables of commercial operation such as site occupation, scheduling of operations, local weather conditions and the geographical location of the sites [21]. Site visits helped students, in previous semesters, become familiar with customer-specific operating protocols.

During the COVID-19 pandemic, the DTU Microgrid Lab Setup [22] was fully accessible via the web, was specifically design to include remote, hands-on and flexible experimentation.
This allowed the Danish student groups to engage in remote collaborative learning, even during full lockdown period in Denmark in 2020. The main purpose of the Microgrid Lab Setup was to address the challenges of power engineering in that, to quote, “today’s power engineering profession requires a more diverse skill set and broader knowledge than in the past”, [23], and at the same time address the increased complexity of Power Engineering [24]. Thanks to the virtual international collaboration strategy of this study, the Mexican students had the opportunity to learn about the remote laboratory facilities, participate in a webinar conference with the conceptual aspects of an intelligent microgrid and additionally they were able to participate in a remote practice with the generators, electrical systems, the control system, grid synchronization, frequency droop control, and automatic voltage regulation (AVR). In Figure 3 is shown a frame collection of different instances of the experience.

Laboratory Practice #1:
- Demo how to synchronize the generator to the grid
- Demo how we can enter a “dispatch” power setting for our generators, and the PID controller will regulate the induction machines’ speed automatically – like a governor in a power plant, to deliver the “dispatched” set-point power to the grid.
- Demo how we can either supply, or absorb reactive power from the grid by running the synchronous generator either over- or under excited respectively.
- Demo how we can operate our three machines as a microgrid
- Demo how the frequency droop controller adjust the dispatch set points to maintain an active power balance in the microgrid
- Demo how the AVR controls the reactive power in the microgrid to maintain a constant bus voltage

Fig 3. Danish lecturer with Mexican students in different instances of the experience (Course TE3053).
Findings, Results and Discussion

In the weeks prior to the beginning of classes, various surveys were carried out among the students of both courses to sensitize them about the experience of interventions that were to be carried out in the virtual classrooms with foreign lecturers. Figure 4 shows the responses obtained to the question of the type of intervention preferred by the students.

![Figure 4: Previous survey carried out with the 47 students of the sample.](image)

In order to verify that the students of the experimental group and the control group had similar initial conditions of their Education 4.0 skills, the results of diagnostic PreTests in both groups were compared. Initial comparison between groups where PreTests have been applied revealed no significant differences in their skills background, as shown in Figure 5.

![Figure 5: Pre-Test Skills levels measured before the study and during the interventions.](image)
Figure 6a shows the impact of the international experiences in Experimental Group. It can be seen that there is a strong correlation between the grades that the students obtained in final scores with the evaluation of the six competences in the PostTests (Creativity, global citizenship, innovation, use of technology, critical thinking and interpersonal skills). The results are similar for both the Experimental Groups, Fall 2020 and Spring 2021.

Figure 6b shows that the control groups obtained significantly lower final grades, considered in relation to the evaluation of almost all competencies, except in the "Use of Technology" which is a skill developed by all engineering students regardless of treatment that they receive, which corroborated our hypothesis that technology is an enabler but not a cognitive tool.

Rubrics were used with the intention of evaluating and discussing learning related to the students' interdisciplinary skills, not the grading. These rubrics allowed positioning the learning within a basic framework of expectations. In order to determine the relationship between creative thinking and the ability of shifting between different modes of thought, the
Pearson coefficient was computed to ensure the possible correlation between results obtained in both PostTests: Interviews and AAC&U Value rubrics.

In addition, determination coefficient R² value was also computed to find the percentage of the total variation in the results of the AAC&U Value Rubrics that can be explained by the linear relationship between them and the results of the other tests. In all cases, and considering that the present study uses social data, the strength of the correlation according to Evans’ criteria (0.6 < r < 0.79, 36% < R² < 64%) can be considered as strongly positive. The findings for the intervention experiences were reported in two sections which reflects the main objectives of the present study: (i) Better understanding of the content and, (ii) Maintaining interest and attention.

**Better understanding of the content.** The results obtained in the final exams and the level of grades in the activities that included interventions showed a substantial improvement in the level of understanding of abstract topics and a better average performance of the students compared to students from previous semesters.

**Maintaining interest and attention.** In both groups, the interventions were well accepted by the students, in addition to showing interest in seeing that the topics that are given in class and applied internationally are the same. This aspect allowed the students to see that they have a good level of preparation and are globally competitive. Another aspect that stands out is that international experiences are highly valued, considering that due to the pandemic they are more restricted. Surveys were conducted where the following comments were obtained:

“I really liked the experience, they complement the learning seen in class”.

“I think they add a lot of value to the class, because in this way there will be greater interest and participation”.

“It seems to me that the guests can also be a source of motivation and inspiration for everyone”.

“I am very grateful for professor’s intervention, because he managed to give us a better understanding of his article and the application in particular based on his experience”.

“I liked it a lot because I think that an international expert can transmit knowledge to you is a very good experience to learn from someone who really knows what is happening and what is needed in other countries”.

“I think that it also helps us a lot to see what is being worked on in the world for the future and I think that this helps us to broaden our perspective and our knowledge”.

“It was incredible. I was pleased to be able to live with someone from another country and see how they solve the same problems that we also have in my country”.

“She helped me open my mind and have a more global vision”.

“In my opinion, the interventions were of great help, to open my panorama of industries that exist around the world and that there is still much to solve as engineers”.

**Discussion on the collaborative learning approach.** The courses in which the interventions were carried out were chosen among those taught with the methodology of collaborative learning and aimed at solving engineering problems. Specifically, the study showed that innovation and creativity skills, both in terms of abilities and dispositions of temperament, can be exercised using the international collaboration approach in fully online settings.
Discussion related with the practice of webinars interventions. The results showed that webinars interventions with international instructors established a common language and that extra knowledge was developed from the shared experiences. It could be verified that the work of the heterogeneous global groups also favors self-motivation (achieving personal goals independently of external influences), self-awareness (being aware of one's own thoughts, behaviors and feelings), and personal ethics (to face ethical dilemmas and technological characteristics of the engineering context).

Conclusion

In the time of COVID-19, the Fourth Industrial Revolution has become a catalyst for new strategies for the higher education sector. The findings support the evidence that Active Learning and Challenge-based Learning approaches are highly effective for the development of several skills in engineering students, including: Global citizenship; Collaborative learning; Innovation and creativity, Complex problem-solving and Analytical thinking. The current panorama is especially detrimental for educational institutions in Latin America. In this particular circumstance, the need to explore new models for developing international cooperation, negotiation and leadership became evident. The preliminary results and findings of this study indicate that international virtually collaboration could be an effective strategy to train students with international skills and to develop certain personal attitudes such as enthusiasm, motivation and intellectual engagement.

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