1.3 Didactical Considerations

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Online Labs in Engineering Education: the Experience of SimuLOPS Lab

Abstract

During the pandemic crisis related to the severe acute respiratory Covid-19 syndrome (SARS-CoV-2), we had to redesign the education system at all levels, from primary schools to undergraduate and postgraduate academic courses. Because of the emergency, we, therefore, realized that traditional teaching models, at least in a university environment, can greatly benefit from the intelligent use of the latest advantages in the Information and Communication Technologies (ICT) sectors.

This paper describes the development and testing of a new teaching and learning system that integrates traditional with virtual approaches to undergraduate education in the field of industrial engineering. The approach was specially designed and developed for undergraduate students in mechanical and automotive engineering with poor, or no, knowledge of the optimization of complex production and logistics systems. The basic idea of the approach is to integrate more traditional university training methodologies, although provided through a virtual learning platform, with Experiential and Laboratory Learning (ELL) provided in both virtual and traditional ways.

We believe that it is time to innovate and implement a holistic educational system, which allows the integration of traditional classroom educational experiences, with new and more modern experiences obtainable through the virtualization of educational activities, in an intelligent way and in such a way as to allow students to autonomously initiate self-assessment processes.

Keywords

Virtual Lab, Digilab4U, Industrial Logistics, Operations Management, Experiences.

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1 Introduction

Over the past two years, the pandemic crisis linked to the severe acute respiratory Covid-19 syndrome (SARS-CoV-2) has profoundly challenged many of the established habits of our world, including how we teach. Universities and other educational institutions were forced to replace traditional teaching approaches (e.g. face-to-face lectures or teaching in physical laboratories) with distance teaching. Taking advantage of this opportunity, many universities modified their courses, both laboratory-based and theoretical, including in the STEM (Science, Technologies, Engineering, and Mathematics) disciplines, in line with the recommendations of the National Research Council (2006).

Making engineering education available online is considered by many researchers to be one of the biggest revolutions in the modern education system (De Jong *et al.*, 2013 ; Waldrop, 2013). Online labs, and with them all teaching activities, can now be optimally used thanks to currently available technologies such as ICT, virtual reality, augmented reality, cybersecurity, and others.

Our experiment concerns the transition of a traditional laboratory into a virtual one for mechanical and vehicle engineering students. The laboratory aims to teach students how to optimize logistics and production processes in industrial plants. Engineering students who have to learn these topics often face several problems in understanding the algorithms behind the optimization logic and translating them into computer programs. Many researchers claim that this is a complex and difficult learning process (Areias *et al.*, 2007 ; Lahtinen, 2010). Students are required to understand the issues related to logistics and production processes and, at the same time, to understand the optimization algorithms; moreover, they frequently have to make additional efforts to learn horizontal topics such as probability, statistics, operations research, and simulation and translate them into a computer program.

To overcome these difficulties, many STEM education initiatives that make use of the virtualization of educational laboratories have been developed all over the world in recent years (Zhu *et al.*, 2016). These include the Malaysian Smart School Implementation Plan (Malaysia), Intelligent Nation Master Plan (Singapore), Smart, the multi-disciplinary student-centric education system (Australia), SMART (South Korea), New York's Smart School (United States), SysTec (Finland) or Mohammed Bin Rashid Smart Learning Program (United Arab Emirates). These initiatives, mostly conducted with small-scale pilots, provide useful guidelines and considerations for

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the design and provision of virtualized intelligent learning environments for STEM disciplines.

Drawing inspiration from these experiences, this paper reports the results of a pilot project conducted at the "Enzo Ferrari" Engineering Department (DIEF) at the University of Modena and Reggio Emilia. The experiment consists of virtualizing the SIMUlate Logistics Operation and Supply chain Lab (SimuLOpS): the idea of the SimuLOpS Virtual Lab is to integrate more traditional university training methodologies with virtualized Experiential and Laboratory Learning (ELL).

By adopting the proposed approach in two university classes of mechanical engineers, excellent learning results were achieved in a learning-by-doing approach, even for students with poor or no knowledge of the subject in question. The test, carried out on 66 students randomly divided into two equal groups, showed that the group that attended the blended learning model achieved better results in the final test. Furthermore, the students who took part in the test, answering a simple satisfaction questionnaire, showed higher satisfaction than the others.

2 The SimuLOpS Lab

The "Enzo Ferrari" Engineering Department (DIEF) at the University of Modena and Reggio Emilia has a wide range of teaching and research labs, where students of master's and Ph.D. courses carry out experimental activities, exercises, projects, and theses. Lab activities reinforce the skills acquired through studying and allow the balanced development of engineering education through the individual and/or group execution of experiments and projects.

Among these labs, a new one has recently been set up that allows students to deepen their knowledge in Operation, Intralogistics, and Supply Chain processes optimization. The SimuLOpS Lab was designed for master's degree students in Mechanical and Vehicle Engineering who have little or no knowledge of the above topics.

The Lab was organized in a traditional way, that is, students were grouped in small teams, with a maximum of three students per team, and the activities were provided through a mixture of lectures, classroom exercises, and computer-based exercises. The activities were carried out independently by the students in a classroom under the supervision of the lab tutor. When the students knew enough about the subject, they were assigned specific tasks (both individual and group) concerning (i) solving one or more pro-

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blems using Excel and VBA, and (ii) analyzing articles/problems provided by the tutor, replicating the solution in Excel and VBA.

The Lab is organized as a classic computer lab, whose goal is not to teach students how to program but to know how to solve industrial engineering problems through the development and application of multi-criteria techniques such as discrete event simulations and algorithms through the use of ICT tools.

With the pandemic, the laboratory was virtualized and linked to traditional teaching. This required a radical redesign, not in terms of the specific contents (still linked to the optimization of logistical and production projects in industrial plants), but in terms of how students can use the lab.

The laboratory activities were organized by combining active learning methods (i.e., providing didactic support, but leaving the learner the task of learning through his or her autonomous activity) and permissive learning methods (i.e., providing materials to the learner, who has the task of working his/her way through the learning unit). Then the exercises were rethought, creating a mix of individual exercises and group work. All the infrastructure was created and shared using the open-source Moodle course management system.

First, a compulsory placement test was created for all students. The self-assessment test, a mix of closed-ended questions and small exercises, is designed to check whether a student has the necessary prerequisites to successfully follow the laboratory activities, namely (i) Excel programming skills at beginner level, (ii) good reasoning/analysis skills, and (iii) basic knowledge of applied optimization and simulation, probability statistics, and operations research.

If the self-assessment test is not passed, the system warns the student that he/she should bridge the gaps in his/her knowledge.

Subsequently, the workshop is organized into 3 modules, each of which includes:

- recorded video lessons with teaching materials, mainly for in-depth study of the theoretical part;
- exercises to be carried out individually, uploading the results online and independently verifying that the exercise has been passed; the exercises must be uploaded onto a specific portal that is visible to the tutor for any evaluations/corrections;
- analysis of the data obtained by carrying out a small simulation on a specific problem created by the tutor; the analyses must be carried out individually and uploaded onto the portal; at the end of the upload,

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comparative templates are provided to understand whether the analyses have been carried out correctly;
- learning self-assessment tests, which are accessible directly from the platform, that provide the students with the correct answers.

After the initial self-assessment, the student has access to the first module only after having (i) watched all the video lessons, (ii) performed all the exercises by uploading the results and the required documents, (iii) completed the data analysis, and (iv) passed the self-assessment before going on to the next module.

Students who complete the three modules are put together in a team of 3 people and each group is assigned a task to do together. The work will be presented to the tutor; only when the tutor gives a positive evaluation of the work will the students be able to sit the final examination.

3 Preliminary experiences

The activities of the SimuLOpS Lab were integrated into two lectures given for the Mechanical Engineering MSc courses, held in the teaching periods *March–June 2021* and *October–November 2021*. The two classes were randomly divided in half: half of the students attended only the classroom lectures (we call this set of students Cluster0) and the other half attended the virtual laboratory as well (we call this set of students Cluster1). The total number of lecture hours for the two groups of students was the same, but the way a part of the teaching program was used for a total of 3 European Credit Transfer and Accumulation System (ECTS) changed.

The analysis of the grades obtained by the students, as reported in Figure 1, shows that students in *Cluster1* obtained a higher average grade than those in *Cluster0* (26.0 compared to 24.4 out of 30). What is interesting is the variability of the grades: with a slightly higher average grade, almost all the students in *Cluster1* have grades close to the average (e.g., lower variance) than those in *Cluster0,* which show a higher dispersion of the grades compared to the average.

All the *Cluster0* students, those who did not attend the lab, were given the chance to repeat the test after attending the virtual lab. The interesting fact, even if this was limited to only 13 students, is that after attending the virtual lab and repeating the test, all the students significantly improved their evaluation (obtaining an average grade of 26.3 out of 30).

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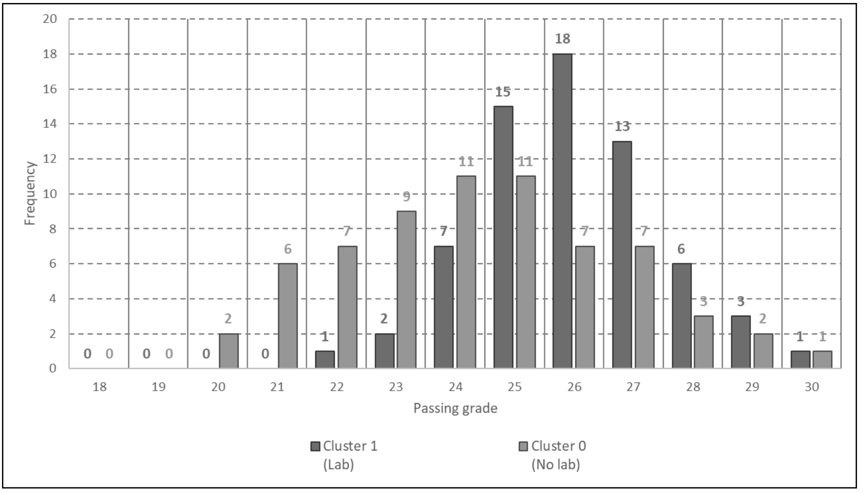

Figure 1: student grades for the two clusters (Cluster0 and Cluster1).

To confirm the students' interest in the lab activities and to indirectly assess the quality of the proposed solution, the 66 students of *Cluster1* were given (at the end of the course and before taking the exam) an extremely simple questionnaire. The first three questions, the answers to which are shown in Figure 2, reveal a generally high level of satisfaction; the students considered it very useful (or essential) to integrate the laboratory activities, including virtual ones, with more traditional teaching activities.

The analysis of the answers to the following questions (shown in Figure 3) suggests some lines of development/improvement of the workshop. On the one hand, it appears that, although the lab activities were not considered too complex, the students engaged in them complained about their lack of previous knowledge preventing them from following the activities effectively. These responses may suggest that the lab should be supplemented with additional optional modules that can be taken freely by students to fill in the gaps in their knowledge (essentially related to probability, statistics, operations research, and programming).

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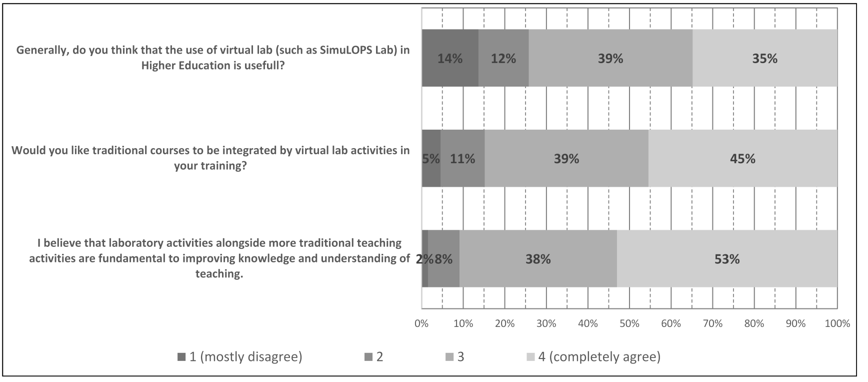

Figure 2: Students' general interest in the lab's activities.

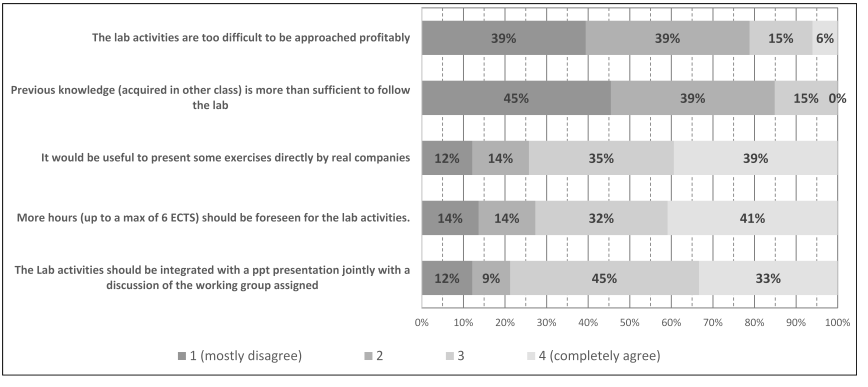

Figure 3: some suggestions collected from the questionnaire for improving the workshop.

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Two other interesting conclusions that can be drawn from the analysis of the answers concern, on the one hand, the possibility of presenting some problems from companies and, on the other hand, having collegial moments of discussion of the group projects assigned.

The workshop could then be supplemented by some companies presenting real problems that the students in groups could face and solve. The resolution could be discussed publicly (both with the companies and with the other students) and part of the final evaluation could be attributed to considering the students' ability to manage the presentation of the results.

4 Conclusions and future developments

This paper describes an innovative approach to teaching industrial engineering topics (i.e. optimization of complex logistics and production systems). The innovation consists of the development and integration of a virtual environment (i.e. a virtual lab) with teaching and lab experiences, specifically designed and developed for engineering students.

The model and the virtual environment were built so that a holistic teaching and training approach was possible. Different training approaches, such as traditional teaching lessons, guided exercises, online lessons, virtual laboratories, teamwork, and intermediate and self-learning tests, were combined.

The model was developed in a rudimentary way and the first tests were carried out to confirm the quality of the solution and to collect appraisals for its improvement. Two classes of about sixty master's degree students each attended the lessons. For each class, half of the students had a traditional teaching method and the remaining half made full use of the virtual resources of the lab. The overall teaching hours were the same for the two groups of students.

The results of the final exam show that there was significantly better preparation on the part of students who made full use of the virtual resources on offer than those who had a traditional teaching approach. Moreover, from a feedback questionnaire given to the students, a greater degree of satisfaction on the part of the students attending the lab emerges.

For the future, the system will have to be extended and tested in a larger classroom, integrating the online teaching modules with cyclical self-tests for the students on past topics as the program progresses. Similarly, more group tests/experiences will have to be integrated (which were lacking in the first test conducted) to facilitate study and preparation activities in groups. Finally, it would be appropriate to develop a proficiency-level entrance exam

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that allows teachers to evaluate the students' starting skills level and to profile the correct lab path—to be combined with traditional teaching activities—based not only on any gaps but also on students' personal attitudes.

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