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Active Learning in Distance Education of Crude Distillation Unit by Virtual Immersive Laboratory: the Eye4edu Project

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The use of virtual immersive laboratories is an appealing and synergistic possibility for education in science, technology and engineering, complementary to experimental activities performed in laboratory or exercises delivered in traditional rooms.
A new educational project, called Eye4edu, proposed different exercises on a virtual immersive Crude Distillation Unit (VCDU), with the aim to apply an active scenario for the learning of the structure of the single unit operations, the whole plant and the control and intervention operating procedures. The project was proposed to the bachelor and master students for the degree in Industrial Chemistry in the Milan University in the years 2019 and 2020. VCDU is based on the combination of the action of “Aveva XR for Training”, formerly Eyesim, and Dynsim software, from Aveva Company, for the physical representation and the dynamic chemical behaviour of the plant.
Several exercises on the plant were proposed to the students both for practical and management operations in the plant. The students were required to work on the basis of the information available in the technical documents, as PFD and P&ID. The project was proposed both in presence and as distance learning, respectively before and during the health emergency due to SARS-CoV-2 pandemic. The description of the virtual laboratory and an analysis of its use and educational impact in face-to-face and remote delivery is reported in this paper.

1. Introduction

Degree courses in chemical engineering can be delivered using traditional teaching approaches, classroom exercises and real experiments in laboratories. In recent years, innovative teaching methodologies have been developed thanks to the use of simulation science (Pirola, 2019). Among these new approaches, collaborative learning in which students cooperate to discuss about results and to solve tasks resulted to be effective and stimulating (Gillies, 2019). Several learning methods can be proposed with active contribution, as analysed by Woods (Woods, 2014), with consequent advantages and limitations (Downey, 2005).
Nevertheless, practical experimental activities in the form of laboratories still represent an indispensable training for an industrial chemist or a chemical engineer student (Hofstein, 2004). On the other hand, the increasing number of students, the cost of the practical exercises (reagents, consumables, time of teaching, assistants, etc.), the safety aspects (possible use of toxic and dangerous substances) are increasing the interest towards virtual laboratories, as reported on Nature by Jones (Jones, 2018).
An innovative and appealing possibility, discussed in a recent review (Potkonjak et al., 2016), complementary to traditional exercises proposed in room or laboratory, is the use of virtual immersive laboratories for education in scientific areas. The most important tools, on which this approach is based, are computer graphics, augmented reality, computational dynamics and virtual worlds. In particular, for chemical plants sector different software simulate both field and control room environments. Dynamic simulation and graphical representation of the real plants are the basis for the development of these software. When an action is taken on the virtual plant, the simulator propagates the effects of that operation up- and downstream (Patle et al., 2019). Nevertheless, few examples are available in the open literature about software that represent virtual immersive chemical plants, or unit operations present in the same plants. Some examples are an ethylene plant for operator training (Sangaran and Haron, 2017), the virtual crude distillation unit described by Norton et

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al. (Norton et al., 2008), but only for the graphical representation of the plant, the polymerization plant described in the ViRILE (Virtual Reality Interactive Learning Environment) project (Schofield, 2012) and the Virtual Crude Distillation plant for the Eye4edu project (Pirola, 2020). This last project, whose acronym means EYEsim for EDUcation (Eye4edu), was based on the use of the "AVEVA XR for Training", formerly Eyesim software from Aveva company and it was addressed the students on the third year bachelor degree in Industrial Chemistry in the University of Milano (Italy). The immersive virtualization of the plant was obtained by Eyesim software, while the behaviour of the plant, from a chemical-physical point of view, was obtained with the dynamic simulation performed by Dynsim software, always by Aveva. The combination of these two software allows to enter and interact with the Virtual Crude Distillation Unit (VCDU), in a way very near to the reality for both the physical structure and the physical-chemical representation. Moreover, the dynamic representation, time dependent, trains the user for the control configuration and strategy of the plant.
Eye4edu project was proposed to 34 students in the year 2019 with different kind of exercises, like the visit of the plant by reading the technical documents (PFD, PID) or some specific actions concerning the use of valves, pumps, units. The quantification of the learning impact was evaluated with devoted test before and after the Eye4edu exercises and the result was very positive (Pirola, 2020).
During the year 2020, it was not possible to proceed with new Eye4edu exercises in presence during the health emergency due to SARS-CoV-2 pandemic. For this reason, new exercises compatible with the distance teaching methods were prepared and developed. The main idea was to operate by sharing the computer screen where the exercises were carried out by the teacher, always discussing each action with the connected students. No other similar educational activities, in which a virtual visit and virtual exercises in a virtual chemical plant were proposed as distance learning are described in literature.
The teacher was the user of the computer with the Eye4edu software and all his actions were transmitted online to all connected people. The students had at their disposal the technical documents of the system and the texts of the exercises with the required elaborations. The obtained results and the opinions of the students about this new active teaching method are reported and discussed. The present paper is mainly devoted to the description of the distance exercises performed in 2020 during the pandemic situation, while the description of the face to face activities delivered in 2019 was reported elsewhere (Pirola et al., 2020).

2. Experimental

2.1 The virtual Crude Distillation Unit and the Software

The virtual Crude Distillation Unit is able to process 170.000 BPSD (Barrel Per Stream Day, equal to1130 m^3/h) of crude. Two parallel crude preheat trains, two desalter units in each train, one pre-flash drum, one crude charge heater and the crude column section are the main units present in the plant. The crude oil is separated in off gas, wild naphtha, kerosene, light gas oil, heavy gas oil and atmospheric residue. The detailed description of the plant is reported elsewhere (Pirola, 2020), while the general overview of the plant is shown in Figure 1.

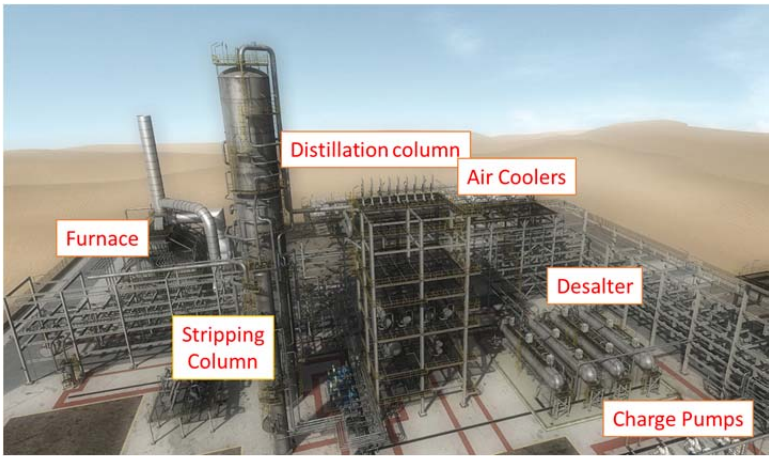

Figure 1: Virtual Crude Distillation Unit overview with the indication of the main units.

The technical documents of the VCDU plant are available for the students. In particular, a general Process Flow diagram (PFD) and 17 Process and Instrumental Diagrams (PID) can be used as supporting material during the visit of the plant and the field exercises. The PFD was published previously (Pirola, 2020). An example of a part of PID for the desalter unit is reported in Figure 2. Due to the complexity of these documents and the smallness of the characters used, it is not possible to report an intact document in this paper.

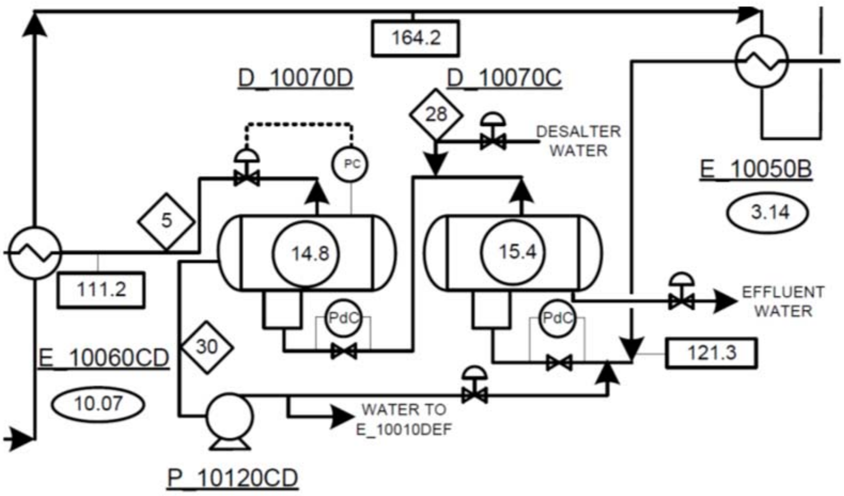

Figure 2: Example of a small part of the Process & Instrumental Diagram of the Desalter unit of the VCDU.

Eye4edu project is based on the use of Eyesim software, by Aveva, in which the crude distillation unit plant is virtualized. Eyesim exchanges continuously the information, as input/output data, with Dynsim software for the dynamic simulation of the plant. The dynamic simulation is achieved by the mathematical equations of the different unit operations, the transport phenomena and the thermodynamic models involved in the separation units. Moreover, the same software is able to reproduce the process control system. Dynsim and Eyesim are connected by a third software, i.e. a Simulator Bridge: it gives a bidirectional communication between the other software. The final result is that all the manual actions performed in the VCDU are passed to Dynsim that, in return, sends a feedback and guarantees a realistic performance.
The computer used to run the software was a DELL Precision 3630 Tower with 460W up to 90% efficient PSU (80Plus Gold), Intel Xeon E-2124G, 4 Core, 8MB Cache, 3.4GHz, 4.5Ghz Turbo, Ram: 16GB 1Rx16 DDR4 2666MHz UDIMM Non-ECC, Solid State Drive (SSD): M.2 256GB SATA Class 20, Hard Disk Drive: 2.5 inch 1TB 7200rpm SATA and graphic card NVIDIA GeForce (1060 6GB). The immersive world was obtained by Oculus Rift S system.

2.2 The Virtual exercises

In the first edition of the Eye4edu project, made in summer 2019, different exercises were proposed to the students as face-to-face teaching in a specially prepared virtual classroom. During the present year 2020, these activities were absolutely not allowed due to SARS-CoV-2 pandemic. For this reason, two new exercises were prepared deliverable as distance learning, thanks to the sharing of the main computer screen. These exercises were labelled as “Distillation Column Operation” and “Sequential Patrol Heat Exchanger”. Moreover, the general visit “Take a tour” to the plant was carried out to show its characteristics and explain how it works to the students. In this activity, the continuous reference to the technical documents of the plant was a fundamental didactic support. Students can observe the shared visit in the VCDU plant, using the operator avatar, and see the free tour around the environment, as they would expect to see things in real life. In this option, the students have to consult the PFD and the different PID of the plant and to connect them with the real plant. Students must begin to orient themselves in the system, understand where the plant starts and then follow its development. They must also observe and understand the details of each area and of the various instrumental schemes in reference to the different PIDs. This exercise is challenging because it is not easy to identify all the parts of this complex system and understand how it works. The “take a tour” experience is also very important because it allows students to know all the most important characteristics of the software, described by the teacher always in screen sharing mode. Furthermore, at the end of this work, the students should have a clear understanding of the physical and structural arrangement of all parts of the VCDU.

The aim of the “Distillation Column Operation” was to control some working parameters of the main VCDU distillation column, to inspect the inside of the distillation column and to answer to three quiz (proposed from DSC, Distributed Control System) about the flowrate of vapor and the values of temperature and pressure. The aim of the “Sequential Patrol Heat Exchanger” was to work on the heat exchanger E-10130A that decreases the temperature of the OVHD (Overhead) vapor line. The temperatures of the crossing lines must be checked and adjusted. For both the exercises, it was suggested as preliminary work to read the actions of the mission, to identify the zones of the mission in the PFD and PID of the plant, to check the design values of the parameters involved in the mission, to analyse and discuss the aims and the operating protocol of the mission.
After these exercise in the field, students are asked to answer questions regarding the work done, to identify in the PFD and in the corresponding PID the units, valves and instruments used and to answer some questions of understanding on the trends of the parameters of plants observed following the operations performed. The PID scheme used in these exercises are reported in Figure 3 a and b.

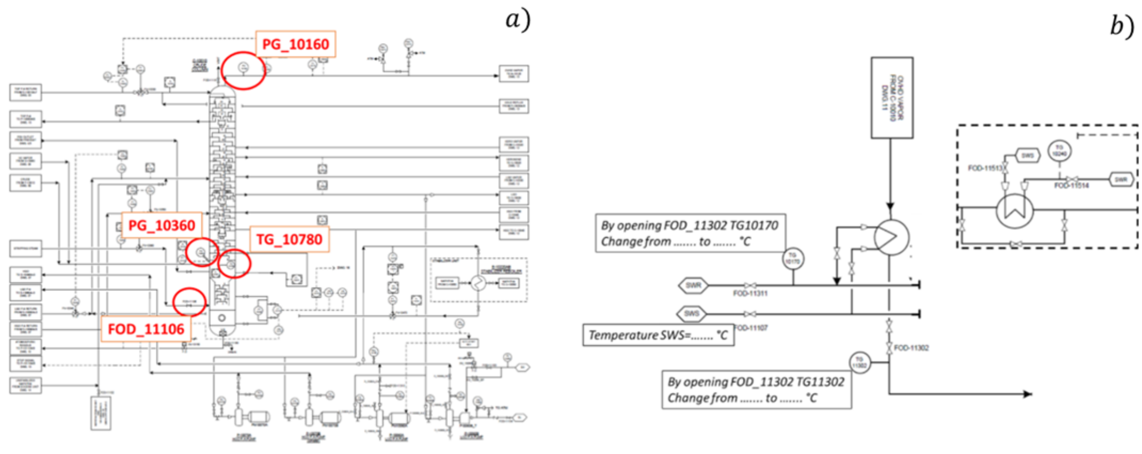

Figure 3: PID scheme for the exercises ““Distillation Column Operation” and “Sequential Patrol Heat Exchanger”.

Carrying out these exercises remotely was a difficult challenge that required a strong interaction between the teacher, user of the software, and the students connected remotely. The three exercises were chosen, from among the many available, because they offered different ideas for interaction, such as reading instruments, managing valves and viewing the different trends of the plant parameters. The speed and timing of execution is a fundamental point. It is in fact necessary to give to the students the time to view the operations carried out, take notes, read the technical documents and detect instrumental values and plant performance. On the other hand, it is also essential to avoid operations that are too long or prolonged interruptions that could cause general decrease of attention. Moreover, it is essential to underline the work procedures and to focus attention on the various details of the plant design with the relative explanations. The recording of the lesson allows students to review what they have done, in order to recover lost operations or explanations not well understood. All these expedients can partially replace time management, freedom of action and the remaking of operations, which are fundamental aspects of face-to-face exercises, where students are directly leading the avatar into the system.

3. Results

The evaluation of the educational impact and performance of the Eye4edu project delivered in distance has been based on a final report in which the students described the VCDU plant, the exercises and reported the results and their elaborations and comments. Moreover, a final survey was proposed to the students with general questions about the value and usefulness of the project. In this project, 36 students took part in 12 groups of 3 people. The choice of proposing working groups was motivated by promoting teamwork between students to stimulate their collaboration and the acquisition of soft skills.
In the final report, each group was asked for the general description of the VCDU system and the detailed description of a specific section, with reference to the relative PID. Each group had to work on a different section. Furthermore, for both field exercises a description of the mission objectives, the working procedure, the tools used, the values of the operating parameters and their trends was requested. Moreover, some

general questions about Crude Distillation Unit theory, plant/equipment and working procedure were proposed, following the examples previously reported (Pirola, 2020). The evaluation of the reports was positive. The VCDU plant and the exercises were described very well. The average mark was 26.5/30. The evaluation expressed in thirtieths is adopted in all Italian universities, where 18/30 corresponds to sufficiency. It is not possible to compare these results with similar project carried out in presence, because in the only previous 2019 edition other exercises and other evaluations were made. As explained, SARS-CoV-2 pandemic forced us to new educational approaches, optimized for distance learning. Nevertheless, the excellent participation of the students and the good results achieved in the final report give very satisfactory feedbacks.
In the final survey 12 questions were proposed about the general evaluation of the Eye4edu project and 4 specific questions for the remote delivery. The opinion of the students concerning the whole interest and evaluation of the virtual plant visit and exercises confirmed the excellent results of the 2019 edition, elsewhere published (Pirola, 2020). These results are not reported in the present paper due to space reason. The 4 questions addressed to the evaluation of the proposal of this project as distance learning and the results are reported in Table 1.

Table 1: Results for the questions of the final survey concerning distance learning.

Question	% of answer for the different questions				
Do you think that the remote version of the Eye4edu virtual visit provided a useful exercise, even if delivered remotely?	Totally Disagree: 2.8 %	Disagree 8.3 %	Neutral 11.1 %	Agree 61.1 %	Totally agree 16.7 %
In your opinion, could it be useful to offer users without the availability of a virtual room (other universities or schools) the Eye4edu exercise remotely?	Totally Disagree 0 %	Disagree 11.1 %	Neutral 5.6 %	Agree 41.7 %	Totally agree 41.7 %
Quantify the level of learning provided by the remote Eye4edu delivery with respect to the same exercise delivered face to face in the virtual room	(0-40%) 11%	(40-60%) 11.1 %	(60-80%) 55.6%	(80-90%) 22.2 %	(90-100%) 0%
Are you interested in repeating the Eye4edu exercise in person?	I don't want to repeat it because I am satisfied with what has been done: 11.1%	I do not want to repeat it because I am not interested in the exercise 2.8%	I want to repeat it if in a short time 41.7 %	I want to repeat it as soon as possible as I am very interested 44.4 %	

The results of the surveys show how the remote delivery of the virtual project had a positive response for about 80% of the participants. The same percentage suggests proposing the project for institutes without virtual rooms as a valid didactic proposal. The level of distance learning achieved is considered to be between 60 and 90% of that in the presence of the majority of participants. Finally, 80% of participants declared an interest in repeating the experience as a face-to-face activity. Of these, about 50% would like to be able to repeat it quickly. The number of participants is not sufficient to consider these results as quantitative. Nevertheless, it can be suitable to consider the opinion of the students about this distance learning project as highly positive.

4. Conclusions

Eye4edu project was proposed to 36 students of the bachelor degree in the Industrial Chemistry in the University of Milan as distance learning. Specific exercises were prepared and optimized to propose this activity as remote exercises, by sharing the screen of the main computer controlled by the teacher. Students participated in a collaborative way and their interpretations and discussions reported in a final reported demonstrated an excellent learning level. The final survey confirmed a high interest and very positive feedback about this project in the students opinion. Distance delivery was considered an excellent educational possibility by most of the students.

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