Immersive Virtual Crude Distillation Unit learning experience: the EYE4EDU Project

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Abstract

The new educational EYE4EDU project, based on proposing to bachelor degree students different exercises on a Virtual immersive Crude Distillation Unit (VCDU), is described. The VCDU combines the action of EYESIM and DYNSIM software from AVEVA Company, for the physical representation and the dynamic chemical behavior of the plant.

The educational impact of the project was quantified. In fact, before using the immersive software, a test with 22 questions was proposed to all participants about the theory of the Crude Distillation Unit plants. After the virtual exercises, the students repeated the test, without further study time, doubling their average rating. In fact, the average marks were 10.5/30 and 20.8/30 before and after the virtual exercise, respectively. The opinion of the students about this project and the software was strongly positive, with an average evaluation of the 14 questions proposed in a final survey equal to 4.58 / 5.

Keywords: Crude Distillation Unit, Laboratory, Immersive Virtual Room, Dynamic Simulation, Separations.

1. Introduction

Chemical Engineer is recognized as one of the most important professional profile that transformed the world and that contributes to technological and social progress. The Occupational Handbook edited by the US Bureau of National Statistics reports that the employment of chemical engineers is projected to grow 6 percent from 2018 to 2028 (U.S. Bureau of Labor Statistics, 2020), with about 34 000 job positions occupied in 2018. The new modern challenges such as global warming, energy problems, the replacement of fossil raw materials with biomass require a high level and multidisciplinary preparation (Seay, 2015). In this context, Chemical Engineering and Industrial Chemistry backgrounds are fundamental prerequisites to develop and create new technologies for the processes of materials that should be more and more advanced and sustainable both from an economic and environmental standpoint (Molzahn, 2004). Therefore, finding alternative and more efficient ways to deliver students the concepts of the subjects is of paramount importance not only for the chemical industry, but also for human society (Cameron et al., 2019). Chemical engineering is characterized by a highly admired curriculum and degree program that require to be fine-tuned to remain relevant to the coming decades (Casassa et al., 2009a).

National Academy of Engineering and the American Society for Engineering Education solicited an improvement of the teaching strategies for students. In a recent study (Prince et al., 2013), a survey was proposed to professors and lectures to gauge their opinions regarding the employment of research-based instructional strategies to improve students' results. However, most of the respondents believed that even though these methods were helpful, they needed a lot of time to be implemented. Among these techniques, collaborative learning (Gillies, 2019) resulted to be very effective, as students cooperate to solve tasks and discuss about results. Different learning methods can be proposed as active approach, as discussed by Woods, (Woods, 2014) with several advantages and limitations (Downey, 2005). For example, to overcome the traditional instructor-centered educational model, in 2016 the School of Engineering of the University of Padova (Italy) pioneered a faculty development program named Teaching for Learning (T4L) (Ghidoni et al., 2019). Digitally coupled learning and innovation processes have been proposed as new way to connect markets and universities, with students transporting the information between these areas (Alger et al., 2019). On the other hand, paired to these new and effective initiatives, practical activities in the form of laboratories remain the most important formation for an industrial chemist or a chemical engineer student (Hofstein, 2004), (Leite and Dourado, 2013). Nevertheless, factors as the increasing number of students, the cost of the infrastructures and the cost for the university (reagents, consumables, time of teaching assistants, etc.), and the limiting factor of using nontoxic and non-dangerous substances lead to the booming of virtual laboratories, as Jones reported on *Nature* (Jones, 2018).

An appealing and synergistic possibility, complementary to experimental activities performed in laboratory or exercises performed in traditional rooms, is represented by virtual immersive laboratories for education in science, technology and engineering (Martin-Villalba et al., 2012). This new approach was discussed in a recent review (Potkonjak et al., 2016), where the authors describe the new emerging technologies that assist the traditional educational approach and overcome some its limitation. In particular computer graphics, augmented reality, computational dynamics and virtual worlds are considered as the most promising tools to propose new educational roads. Robotics is considered as the most advanced area in this context. Many developers created simulated laboratory environments for physical (Foreman et al., 2020), biological (Coêlho dos Santos et al., n.d.) and also to train nurses (Padilha et al., 2019) lessons.

Concerning, instead, simulated chemical plants the examples are rare. Diverse software train operators on chemical plants, that simulates both field and control room environments. More often, these are based on a dynamic simulation and a graphical representation, so that when an action is taken on the virtual plant, the simulator propagates the effects of that operation up- and downstream (Patle et al., 2019). These instruments are expensive and have not been employed to train students, since the simulated plants are based on licensed processes that companies (usually in the oil refinery sector) own. Such a tool could be of a huge impact on students, since they could learn and operate virtually on an industrial scale plant, where safety protocols and the dimension of space acquire a different meaning.

In the open literature, few examples are available about software that can represent virtual immersive chemical plants, or unit operations present in the same plants. Moreover, no quantification about the educational impact of these software is reported and discussed in these articles. For example, Norton et al. propose an interesting software based on spherical imagery of real operating plant coupled with interactive embedded activities and content (Norton et al., 2008). The plant represented in this software was a Crude Distillation Unit (CDU) and was constructed by using professional industrial photography of a real plant. Then, the software proposes basically an immersive photographic representation of the chemical plant.

Schofield described its software "ViRILE" (Virtual Reality Interactive Learning Environment), designed for the simulation of a polymerization plant (Schofield, 2012), with a reactor section and three distillation columns. This software was based on several simulation data generated using steady state conditions and C++ programming. Also in this case, no description on the impact of this software on the students was reported.

In the present paper, the description and the results of the EYEsim for EDUcation (EYE4EDU) project were reported and discussed. This project 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 industrial-academic partnership, on which this project was based, can give very synergetic results in educational activities, as discussed for example by Casassa et al. in the field on nanoparticles, macromolecules and interfaces (Casassa et al., 2009b). EYESIM software proposes the immersive virtualization of a Crude Distillation Unit plant with the representation of the detailed realistic graphical 3D of the whole plant. The behavior of the plant, from a chemical-physical point of view, is obtained with the dynamic simulation performed by DYNSIM software by AVEVA. These two software are connected by a third software (bridge) and the final result is the possibility to enter and interact with a Virtual Crude Distillation Unit (VCDU), practically identical to the real plant both for the physical structure and the physical-chemical representation. The dynamic representation is important also to learn the control configuration and strategy of the plant, that is a topic particularly open to innovative educational methods (Bequette, 2019). Crude Distillation Unit is a very complex plant and could be considered as a too difficult case-study for bachelor students. Nevertheless, this plant can be proposed at different levels and it is also possible to discuss, explain and propose virtual exercise on specific units present in the plant, as for example the desalter, the furnace, the pre-flash column and so on. For this reason, the virtual plant can be proposed both as a whole and as specific units, giving the teacher and students the opportunity to choose the type of application most suitable for their specific background and aims.

In the EYE4EDU project, the students' opinion about this activity was evaluated by a detailed survey. Moreover, the educational impact of this proposal was quantified checking the students preparation about CDU plant before and after the virtual exercise. Indeed, before using the immersive software, a test was proposed to all the participating students about the theory of the CDU plants. The test was formed by 22 questions, in three different sections about CDU theory, CDU plant configuration and CDU plant working procedure. After the virtual exercises on the VCDU, the students repeated the test, without further study time at home, and the improvement of their answers was quantified.

2. The course and the students

EYE4EDU project was proposed to the students of the course "Industrial Plant with Laboratory" in the third year of the bachelor degree in Industrial Chemistry at the University of Milan (academic year 2018-2019). This is a fundamental (mandatory) twelve-credits course. The course is divided into two parts (6 credit each): the theoretical part (48 h) and the laboratory part with 80 hours, composed of 16 hours of theoretical lessons and 64 hours of experimental work. The reference teaching material suggested for this course are the books “Processi di Separazione nell’Industria Chimica (Separation Processes in the Chemical Industry) (V. Ragaini, 2016) written in Italian, “The Properties of Gases and Liquids” (R. C., Reid, J. M. Prausnitz, 1988) and “Mass-Transfer Operations” (R. E. Trybal, 1981). The average number of students per year is 60. The students must attend the preparatory courses of physical-chemistry and transport phenomena before taking this course. Furthermore, they have already successfully followed and passed the final exam of the propaedeutic courses, namely mathematical analysis, physics, numerical calculation, general chemistry, organic chemistry, inorganic chemistry, physical chemistry and industrial chemistry. The latter is particularly important as the main chemical plants of the petrochemical and chemical industry in general are treated.

The course focuses on traditional separation processes used in the chemical industry as distillation and absorption. Its program includes the following topics: thermodynamic description of fluid phase equilibria (vapor-liquid and liquid-liquid), basic principles of separation processes, mass and heat balances, sizing of multistage continuous distillation and absorption columns. Moreover, tutorial and some exercises concerning simulation science are proposed to the students. PRO/II by AVEVA is the reference software. Detailed description concerning this course and the structure of the laboratory are reported in (Pirola, 2019). Briefly, all the theoretical concepts are exposed during the 48 hours of the theoretical course. In parallel, in the laboratory course the practical experiences and the experimental plants are described and explained in the 16 hours of theory in devoted classroom lessons, while the experimental activities are carried out in the 64 hours of laboratory. The laboratory work is divided into four stations: 1) determination of vapor pressure of two pure liquids at different temperatures; 2) determination of the vapor-liquid equilibria (T, x, y) for a binary mixture at different pressures; 3) the operation of a multistage continuous distillation column; 4) the operation of a multistage absorption column. The experiences 1)-3) (Pirola, 2019) and 4) (C. Pirola, 2019) were previously reported.

Each student works in group of 3-4 people and the lab attendance is mandatory. Each group is requested to write a final report (prepared by the team), that is discussed individually in the final exam. The quality of the final report accounts 40 % of the grade, the laboratory activity 10 % and the final exam the remaining 50 %.

For the first time, EYE4EDU project was proposed as fifth exercise in the laboratory course in the year 2019. This project is complementary with the laboratory activities because the students, after the classroom lessons concerning the basic theory of separation processes and after the laboratory exercises in which they collected experimental data at laboratory scale, can visit and interact with a immersive industrial plant totally devoted to separation technologies, i.e. a Virtual Crude Distillation Unit, able to process 170000 BPSD (Barrel Per Stream Day, equal to1130 m^3/h) of crude, as described in the next paragraph.

3. Virtual reality environment

3.1 The Crude Distillation Unit Plant

EYE4EDU project is based on the use of EYESIM software, by AVEVA, in which a real crude distillation unit plant is represented in virtual environment. The concept is to provide a realistic process environment to allow the possibility to the students to visit a real plant with no safety or physical limitation and to interact with the parts of the plant (valves, equipment, instrumentation, sampling lines etc.). EYESIM is connected with a dynamic simulation of the plant, executed by DYNSIM software by AVEVA. DYNSIM includes the mathematical equations representative of the basic theory of the different unit operations, the equations for the transport phenomena representation and the accurate and detailed thermodynamics models (different equations of state and models to calculate the activity coefficients) for the representation of all the fluid phase equilibria involved in the separation units. Moreover, the same software features the mathematical equations for process control systems. Combining these models, DYNSIM is able to simulate various process plants including a detailed control system, trip interlocks and electrical distribution systems. The EYE4EDU simulation used is a generic CDU developed to represent a generic but realistic process environment to provide a wide range of training scenarios for operators to train upon and be assessed upon in a classroom. The process model has been constructed from Aveva in-house information and knowledge developed over the years of creating process plant simulations. The process simulation, the control logic and the 3D environment has been validated during a real life project with a customer. Each element has been reviewed with the ultimate scope of training the field operators for different plant situation after the completion of the project.

The EYESIM application has been designed to be operated using a gamepad device, as for example Logitech F710.

This plant processes 170 000 BPSD of crude, and it consists of two parallel crude preheat trains, two desalter units in each train, one pre-flash drum, one crude charge heater and the crude column section. The general Process Flow Diagram (PFD) scheme of the VCDU plant is reported in figure 1, while the map is shown in figure 2.

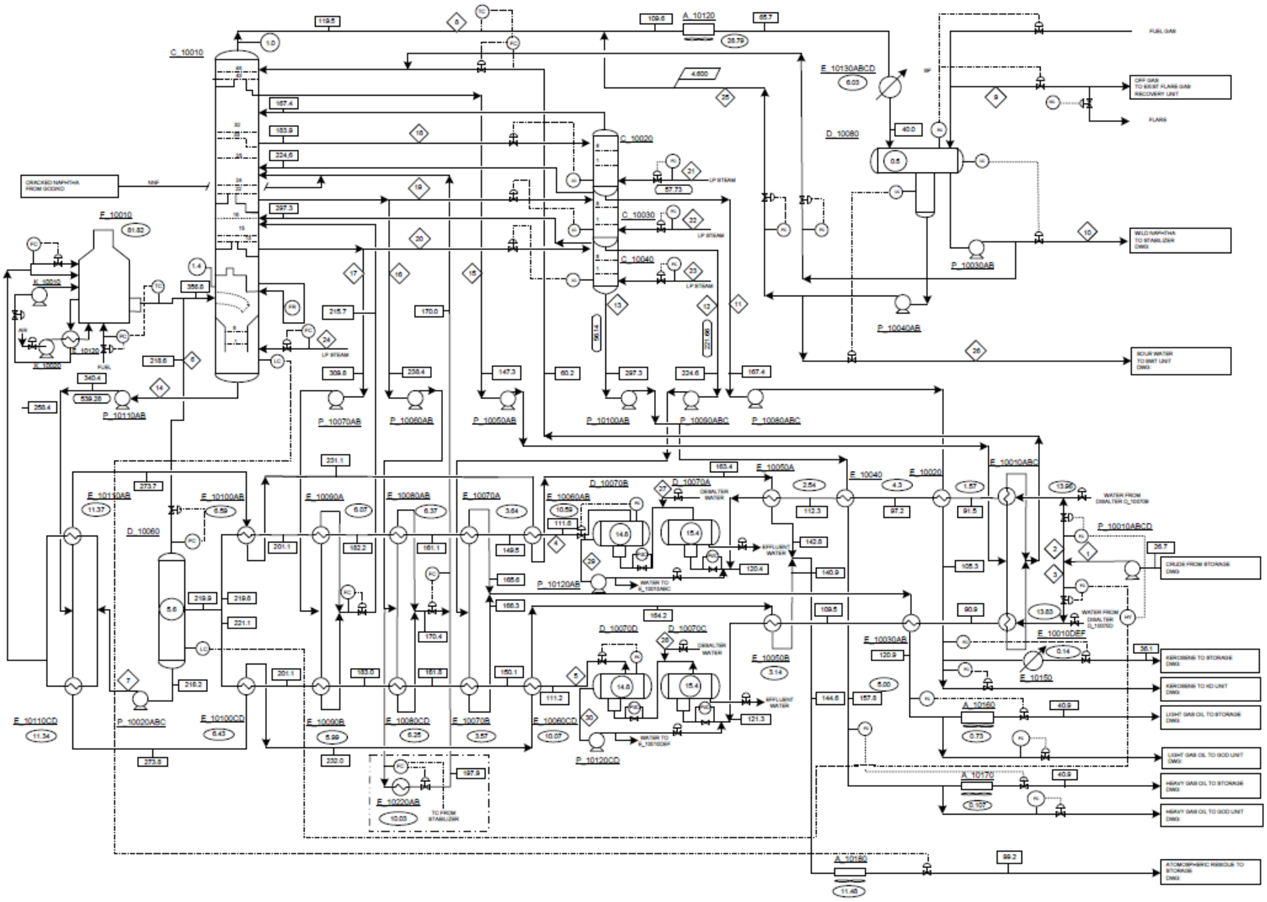

Figure 1: General PFD of the CDU plant

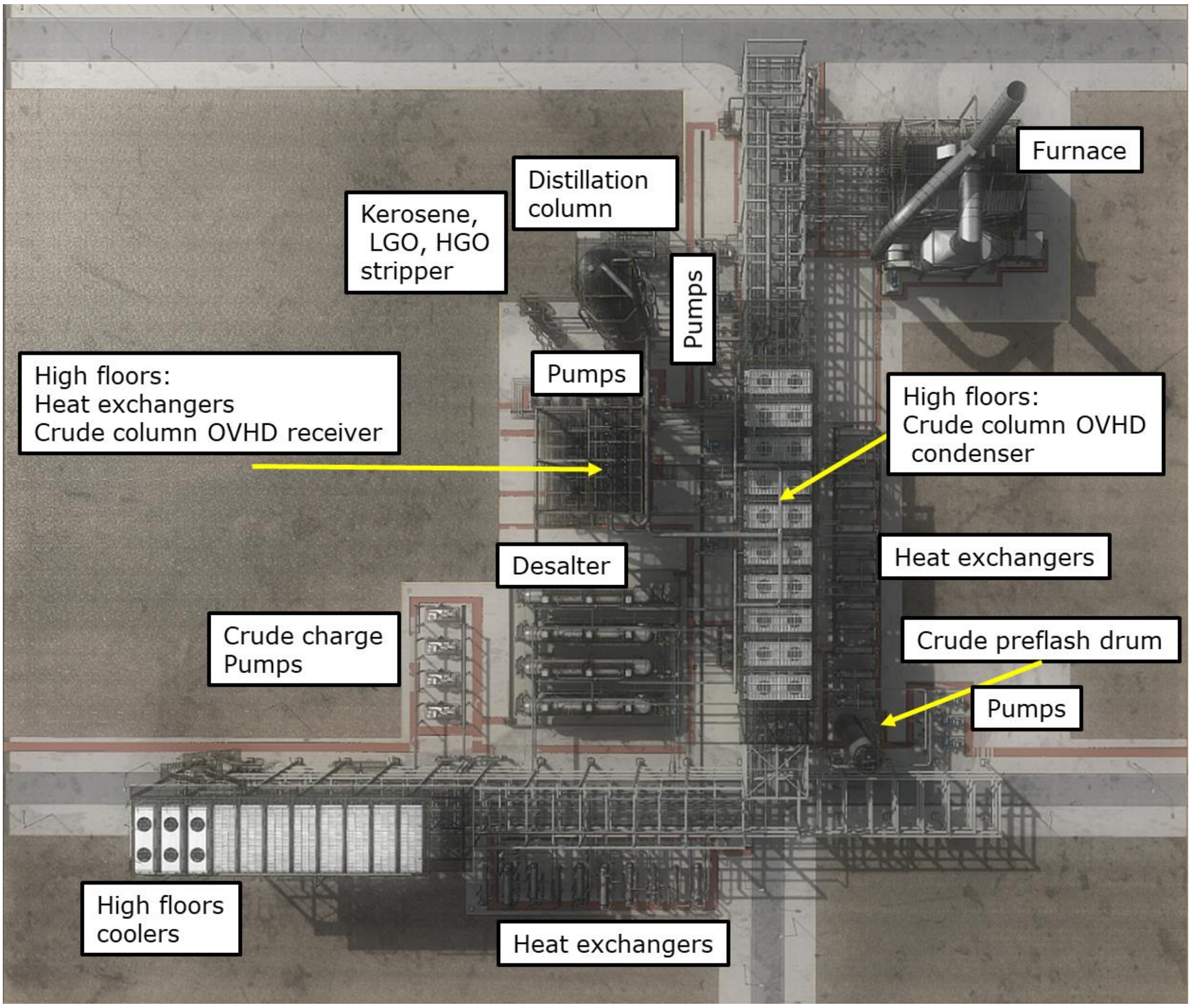

Figure 2: Map of the CDU plant

Heat and mass balance at normal operation conditions for 30 lines of the VCDU plant are reported in the Supplementary Material (Table SM.1).

The crude oil is separated in the crude unit into various fractions as: 1) Off Gas, which is routed to the recovery unit; 2) Wild Naphtha, which is sent to the stabilizer; 3) Kerosene, which is routed to the downstream unit/storage; 4) Light Gas Oil, which is sent to downstream unit/storage; 5) Heavy Gas Oil, which is routed to downstream unit/storage; 6) Atmospheric Residue.

The fed crude oil from storage (P=1 kg/cm^2; T= 26.7°C) is charged and pressurized in the main line by 4 crude charge pumps at a pressure of about 14 kg/cm^2. This line is then split in two lines and sent to the crude pre-heat trains formed by 4 heat exchangers. The crude oil lines are heated by recovering the heat from different distillation cuts to a temperature of 112°C. Then, they enter in a two stages desalter units for the removal of inorganic salts as sodium chloride (pressure of about 15 kg/cm^2). The exiting streams are heated by other 5 heat exchangers to a temperature of about 200°C and then sent to the crude preflash drum column. The crude is maintained under pressure in the pre-heating train to avoid vaporization of light molecules. The pre-flash drum column is a flash unit that separates light components before further increasing the oil temperature in the next heat exchanger and in the furnace. The light components separated in this unit are directly sent in the main distillation column. The not volatilized compounds enter in the furnace where the temperature is increased to about 360°C, by a convective and a radiant zone and then enter, partially vaporized, in the feed zone of the atmospheric column. The components of the crude oil are separated in this unit by steam stripping. Products are withdrawn from the side of the distillation column and three side stripper columns help the control of the composition of light compounds (Kerosene stripper, Light Gas Oil stripper and Heavy Gas Oil stripper). Moreover, liquid phase is extracted in different heights of the column and cooled to be re-inserted in different points by pump-around circuits. The vapor exiting from the top of the main atmospheric column is cooled down by air coolers and heat exchangers and then it is sent in the crude column receiver where water is separated from wild naphtha and off gas. All the exiting streams from the column are used as heating source for the different heat exchangers present in the plant.

The virtual system EYESIM reproduces the real structure of a CDU system in a very faithful way to reality, even in the smallest details. The virtual environment includes also the active plant elements like valves, indicators, motors, panels that are animated. Some of them are virtual representations of physical items while other make use of augmented reality features to allow user to better understand process behavior. The active items can be dynamic and/or interactive. Dynamic means that their aspect change according to one or more variables in the process. Interactive means that virtual field operator can interact with them. All “active elements” are provided with labels and name tags to identify them, reported also in the Process and Instruments Diagram (PID) sheets of each part of the plant available for the students. An example of PID for the Charge Pump Section is shown in figure 3.

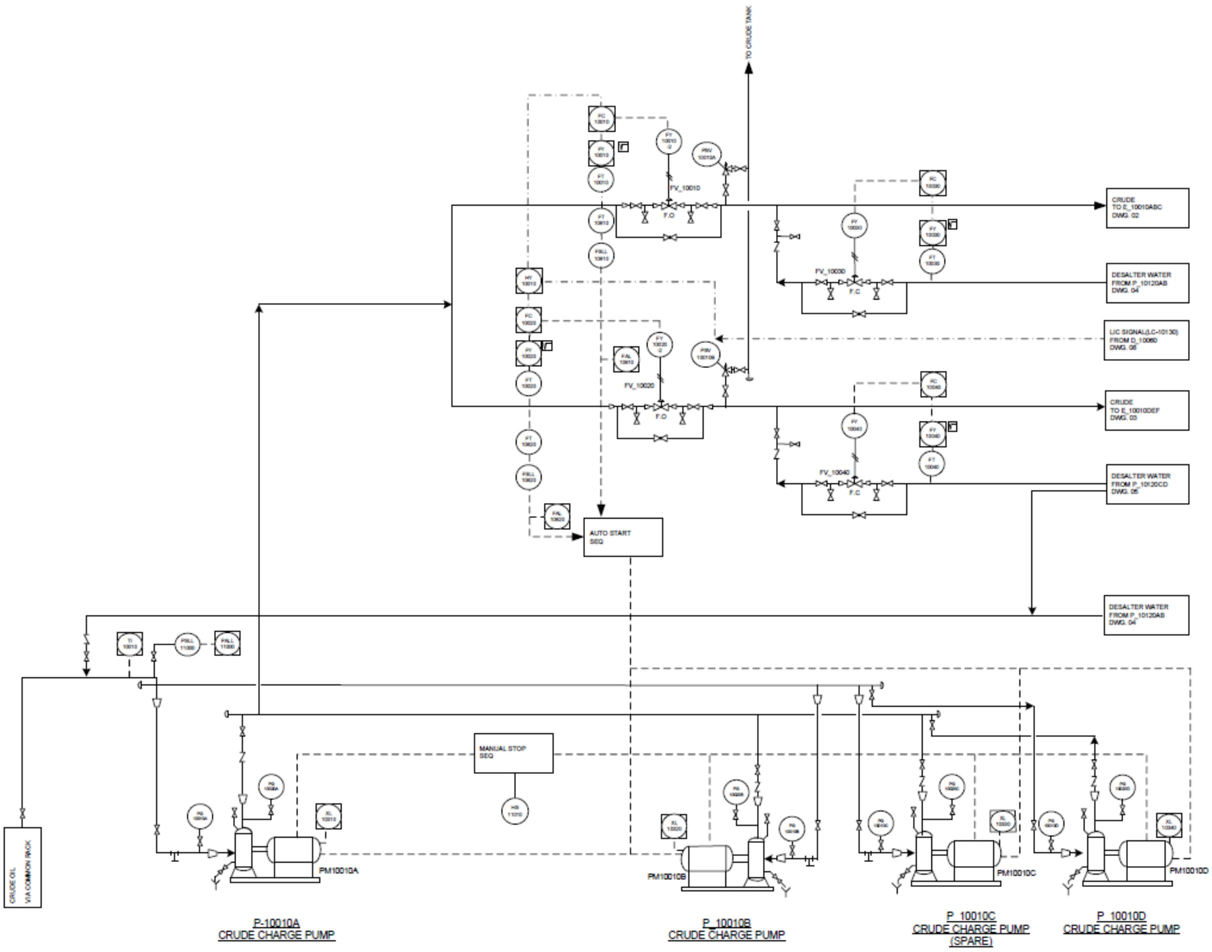

Figure 3: PID no.1 of the VCDU plant for the Charge Pump Section.

The user is able to check the open/close state for all the active valves and to operate the active manual valves and those valves with hand wheel. The active Emergency Shut Down (ESD) valves will be operated through a local panel beside the ESD valve. The representation of the valves in the virtual plant depends on the type and size of valve.

In the virtual plant the pressure, level, flow and temperature indicators or transmitters are represented. User is able to check all the active field measure instruments. Each instrument is reproduced as it is in reality and its dynamic value will be shown according to the instrument characteristics with a gauge or a LCD panel. In addition, some flow transmitters are provided with a trend pop up to show the trend of the flow to the user.

Students are able to check the active motors state and eventually operate them using local panels, that will be modelled to look like corresponding items in a real pant. Moreover, they are able to localize active panels, to view their indicators like pump, gauges and to interact with their commands like buttons, selectors etc.

EYESIM has the capability to provide additional information on top of the virtual environment that would not be visible in a real life but can deliver powerful educational and understanding value. These features are referred to as “augmented Reality” and include variable trends and pop-ups, animation of equipment and overlay of information on equipment (e.g. liquid level). In fact, in the plant are present some transparent panels that allows the students to see inside some equipment.

In some cases, the animations are dynamic and linked to process variable from the DYNSIM model, as in the following units: Crude Charge Heater, Crude Column OVHD Condenser, Crude Column, Trim Condensed and Fire in the Preflash Drum Column.

In the Crude Column is available the animation that represent the vapor and liquid traffic as well as the tray level in the section above the feed inlet, composed of 4 sieve trays. In the normal working condition, the vapor goes up through the tray holes and the liquid goes down through the downcomer. In jet flood condition, the liquid level on the tray increases up to the tray above. In weeping condition, the liquid falls through the tray holes produced by low vapor flow.

In the animation of the furnace, the students can see the flame status in the radiant section through a peephole. The colour, size and shape of the flame is animated for the different combustion conditions depending on the air/fuel gas ratio, combustion heat and pressure inside the furnace.

In the animation of the air cooler, the users are able to inspect inside the unit in order to see all the elements that make up this equipment: structure, motor, blades, fin tubes and louvers. Besides, the students can operate all the air coolers (20 in the plant) from the local panel starting/stopping the motors ar adjusting the louver angle and blade pitch.

A heat exchanger condenser (E-10130A) can be inspected in the internals in order to see the elements that make up this equipment such as the shell, baffles, tubes and also a simplification of the liquid and vapor phases inside the shell, which is connected to DYNSIM. This unit is a shell and tubes condenser type with a bundle of 1036 tubes, 8 tube passes, square pitch and a shell with 18 cross baffles.

Before entering in the VCDU plant, the student must select the right Personal Protection Equipment (PPE) among all the ones available in the menu, depending what kind of mission/exercise in the plant he wants to try. PPE are gloves, torch, breathing apparatus, explosive meter, synthetic apron, hardhat, face shield, hearing protection, safety glasses, vapor respirator, H_2S detector and radio. The PPE can be considered as mandatory, optional or wrong depending on the mission. In fact, the application perform an item check, if some mandatory items are missing or some wrong is selected an error message is presented (“incorrect PPE”) with the details and the students must correct the items otherwise application does not go to next step.

A general overview of the CDU virtual plant is shown in figure 4, while some sample images of the virtual environment are shown in the figure 5.

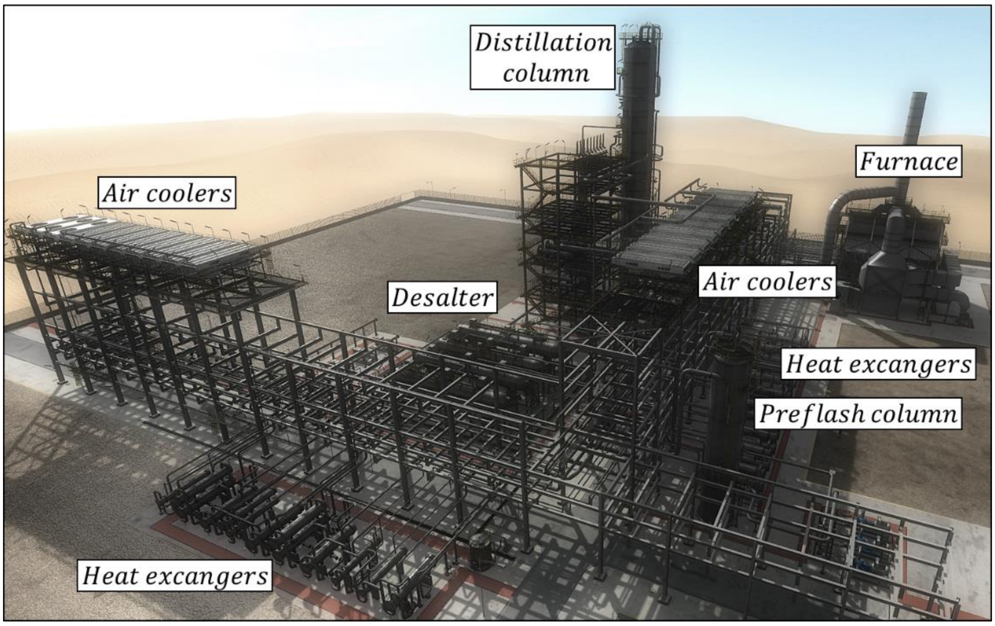

Figure 4: Overview of the CDU virtual plant with indication of the main units.

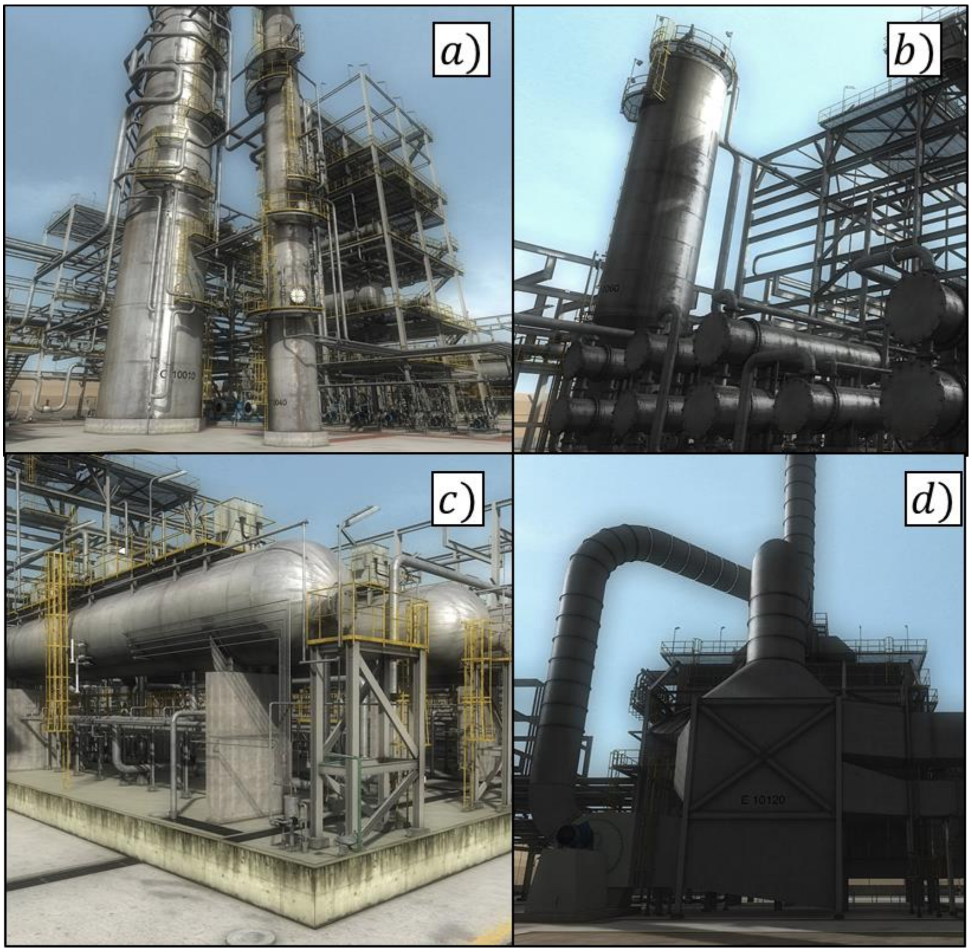

Figure 5: Pictures of some parts of the CDU plant: a) main distillation column (on the left) and pre-flash column (on the right); b) heat exchangers train and preflash column; c) Desalter; d) Furnace.

3.2 Software and imagery

DYNSIM is a general purpose dynamic process simulation program capable of modeling dynamic behavior of process plant through first principles models, including rigorous thermodynamic and fluid flow calculations. It is used in a variety of industries such as Oil & Gas, Chemical, Power or LNG. A well-defined DYNSIM model is subject to the same hydraulic, heat transfer, or other operating constraints as the actual plant. Furthermore, DYNSIM robustly models cold startup from purged conditions to normal operation and then back to shutdown.

A dynamic simulation created in DYNSIM can be used for different purposes, from design validation to operator training. The latter in particular is possible because DYNSIM can be connected to other software such as DCS or PLC emulators. The high-fidelity dynamic simulation plant model reflects the operations and control responses of the actual plant. Operator Training Simulators tie together the Dynamic Simulation with the emulated controls system to provide safer operation while improving performance and productivity. This capability has been expanded into the so called Immersive Training System, because with EYESIM Virtual Reality it is possible to emulate not only the existing hardware and software systems, but the physical plant design and layout, and operator consoles. This creates an interactive, 3D environment for training.

DYNSIM and EYESIM interact through a Simulator Bridge: it allows a bidirectional communication between the two software. This means that every manual action performed by an operator or student in the field is passed to DYNSIM that, in return, sends a feedback and guarantees a realistic performance.

3.3 Hardware

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.

3.4 Learning resources

The total number of students participating in the project was 34, divided into groups of 3 or 4 people. Each group worked in two consecutive sessions, each of a duration of 3 hours. The first session was devoted to a short general introduction to the VCDU plant and the software and then to the visit to the plant “take a tour”. In the second session the students were free to repeat the visit of the plant, for example to explore in detail some specific units (desalter, pre-flash column, main column, furnace etc.) and then to apply for the “in field exercise”, as described in the following. The students feedback was the compilation of the exercise sheets, where a list of required actions to be confirmed was placed, the annotation of some instrumental values of the VCDU plant and the verification of having identified some units and some instruments. Furthermore, after the end of the second session, the completion of the final test was immediately requested.

In the “take a tour” exercise, students can enter in the VCDU plant, using their avatar, and take a free tour in which they walk around the environment as they would expect to see things in real life. In this option, they have to consult the PFD and the different PIDs of the plant (18 in total) and to connect them with the real plant. After some preliminary explanation given by the teacher, they must begin to orient themselves in the system, understand where the plant starts from and then follow the development of the plant following the Process Flow Diagram scheme. 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 discussions between the different components of each group, together with the presence and explanations of the teacher, can allow a learning experience much appreciated by the students.

The “take a tour” experience is also very important because it allows students to get to know the software, the virtual plant and to become familiar with them. 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. After this step, it is then possible to propose to the student to try to make some missions inside the plant. In the application, 16 missions are available with different levels of complexity and duration. These missions are listed and shortly explained in the Table 1 with an overview of the scenario. Each mission is characterized by an appropriate dynamic model, a detailed procedure to follow and a scoring system, based on time in which the mission is performed and the number of right or wrong actions. Missions are put in order of difficulty level.

Table 1: Field Operator-training missions

Number	Training Mission	Description
1	Control valve bypass operation	The student has to operate the bypass of the control valve due to a malfunction of the control valve
2	Start up pump driven by motor	The student has to start the stabilizer feed pump
3	Distillation column operation	The student should check of operation condition of the distillation column and report any abnormal condition
4	Sampling with return line	The student has to take a sample of the atmospheric residue product
5	Sequential patrol	The student should check the temperature of the sea water return in two heat exchangers and fix the one is high
6	Pump operation	The student has to start a pump driven by turbine and stop a pump driven by a motor
7	Airfin cooler operation	The student has to operate the crude column condenser
8	Total power failure case	Patrol after emergency plant shutdown by total power failure
9	Leakage and fire case	The student has to follow the procedure in case of leakage and fire in the discharge of a pump
10	Weather change case	The student should check and adjust the crude column condenser
11	Furnace operation	The student should adjust the furnace condition from imperfect combustion
12	Start-up	The student should start the furnace
13	Total throughput increase	The student should adjust the number of burners, air pre-heater and crude column condenser operation
14	Normal shut down	The student should shout down the furnace
15	Control valve malfunction	The student has to find out the root-cause of a valve malfunction

The students can choose between tutorial or assessment mode for each training mission. In the tutorial mode the operator performs the task using a wizard procedure, viewable at the top left of the screen. In the assessment mode the operator can move within the environment and must perform all the mission without the help of the wizard. Before starting a specific mission, it is warmly suggested to the student to consult the PID of the zone of the plant where the mission will be performed. This is very important to fully understand the meaning of all the actions required in the mission. Also in this case, the discussion and the mutual help between students and the interaction with the teacher is of fundamental importance.

As example, the actions required for the first mission “Control valve bypass operation” are reported in Table 2, while the corresponding PID is reported in figure 6.

Table 2: Action for the “control valve bypass operation” mission.

Action	Operation mode
1	Call radio from DCS-Reply to DCS operator radio call
2	Check FV-10540 – Verify FV_10540 is stuck
3	Bypass FV_10540 – bypass valve controlling that FT_10540 is in the range 185-190 ton/h - Call to DCS operator – Ask DCS operator to keep informed about FT_10540 value while operating bypass - Open FV_10540_BP gradually – should be moved of max 2% a time - Close FV_10540_ISO1 gradually – Close fully the valve should be moved of max 50% a time - Confirm FT_10540 position with DCS operator that FV_10540 is in the range 185-190 ton/h
4	Close FV_10540_ISO2 – close fully the valve
5	Check LG-10050
6	Open FV_10540 drain valves – Open gradually FV_10540_DR1 and FV_10540_DR2
7	Confirm FT_10540 stability with DCS – Call DCS operator by radio to check if FT_10540 is in the range 185-190 ton/h

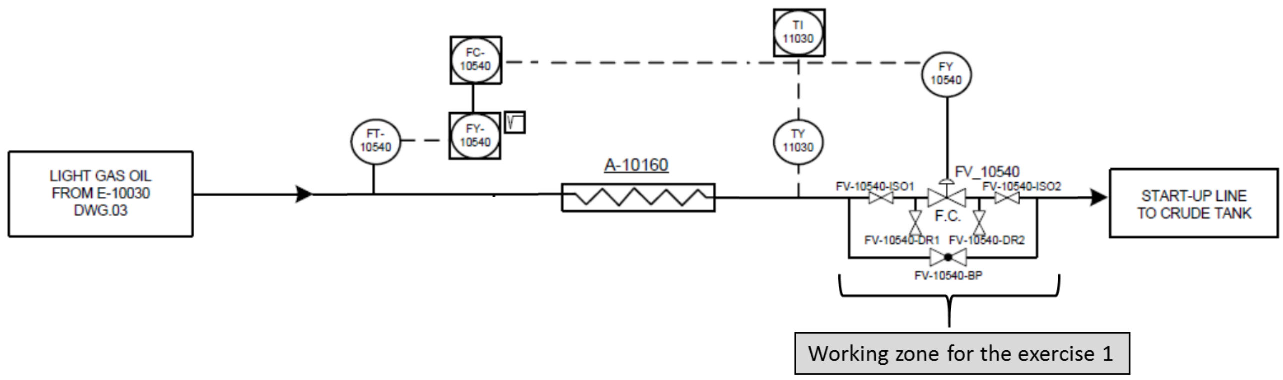

Figure 6: PID diagram for the exercise number 1, “control valve bypass operation” mission.

4. Results

The evaluation of the educational impact and performance of the EYE4EDU project has been based on two different instruments: a final survey proposed to the students with general questions about the value and usefulness of the project and a test about the CDU plant proposed to the students before and after the virtual exercise. In the test, the questions were proposed in three different sections, i.e. the “CDU theory”, the “CDU plant/equipment” and the “CDU working procedures” sections. In the “CDU theory”, 8 questions were defined about the basic theoretical knowledge of Crude Distillation Plants. In the “CDU plant/equipment” section, 11 questions were proposed about the real configuration and layout of the chemical CDU plant. Finally, in the “CDU working procedures” section, three questions were proposed concerning the working procedure typically used in CDU plant. The entire list of questions is shown in table 3.

Table 3: List of the questions proposed in the EYE4EDU test, before and after the virtual exercises.

Question number	Section	Text
1	CDU theory	Explain the function of the "desalter" unit
2		Explain the function of the "Crude preflash drum" unit
3		Explain the usefulness of the stripper column for the "Kerosene", "LGO" and "HGO" cuts and describe in which way this unit is connected to the main distillation column
4		What is the working pressure of the main distillation unit? How could you avoid the thermal degradation of its constituents, especially long chain molecules?
5		In which way is the oil preheated before the distillation column?
6		Why is steam introduced in the lower part of the column?
7		How do the head vapors (coming out of the distillation column) cool down?
8		What is the function of the "pumparounds" circuits?
9	CDU plant/equipment	Considering that the plant processes about 1000 m^3/h of crude oil, and that this amount must be heated from about 25 ° C to about 270 ° C before entering the pre-flash column, how many lines do manage this flow in the plant and how many heat exchangers are present in each line to obtain this temperature increase?
10		In the heat exchangers discussed in the previous point, which streams of the plant can be employed to heat the main oil stream?
11		Briefly describe the shape and layout of the desalters.
12		Briefly describe the shape of the heat exchangers.
13		What is the role of a furnace in the CDU? Describe briefly the shape and size of this unit, the design structure, the way in which heat

		exchange is integrated and indicate the direction of the flow of oil inside it (from the bottom to the top or vice versa?).
14		Where are located in a CDU plant the pumps for the transport of the cuts of the main distillation column (pumparound and connections with the stripper for kerosene, LGO, HGO)?
15		With which equipment does the column head steam cool down?
16		Are the flows exiting from the CDU (various cuts of different products) cooled before entering storage areas? If so, in which way?
17		Is it possible for the operators to get on the equipment (columns, heat exchangers, dasalters ...) or are all the control operations carried out by areas on the ground or by control areas? If possible, how is it possible to get on?
18		Are there glass or transparent "windows" to monitor the processes inside the equipment? If so, what is the approximate size?
19		What is the difference between "operators" and "contractors"?
20	CDU working procedures	If you were at work in the plant, and you saw flames at the base of the distillation column, how would you put in the correct order the following activities: use of the special hydrant, report the accident to the operations center via radio, move away from the event to warn colleagues, move away from the event to alert contractors, shut off oil input pumps, request permission to use the hydrant.
21		Considering the following diagram (see Fig. 6), relative to the cooling line of the LGO fraction, at the end of the plant: if the valve FV_10540 (FV = Flow Valve) malfunctions with what procedure would you take to activate the by-pass? What checks would be necessary at the end of the operation? FT_10540 (FT = Flow Transmitter) must be in the range 185-190 Ton / h.
22		Considering the section of the exhaust system of the storage column residue, as shown in the diagram (PID was given to the students), with what procedure could you sample using the LV_10179_SC3 valve?

Students were asked to answer with open questions, not multiple choice, as usually required in Italian universities.

Test were corrected and evaluated considering for each question a mark of zero in the case of no answer, a mark of 10 for not sufficient answer, 20 for sufficient answer and 30 for very good or excellent answer. The evaluation expressed in thirtieths is adopted in all Italian universities. Following these criteria, each answer given in the test was evaluated. Moreover, a total mark based on the average value of all the answers evaluation was calculated. This work was made for the test taken before and after the EYE4EDU exercise. All the results are reported in figure 7.

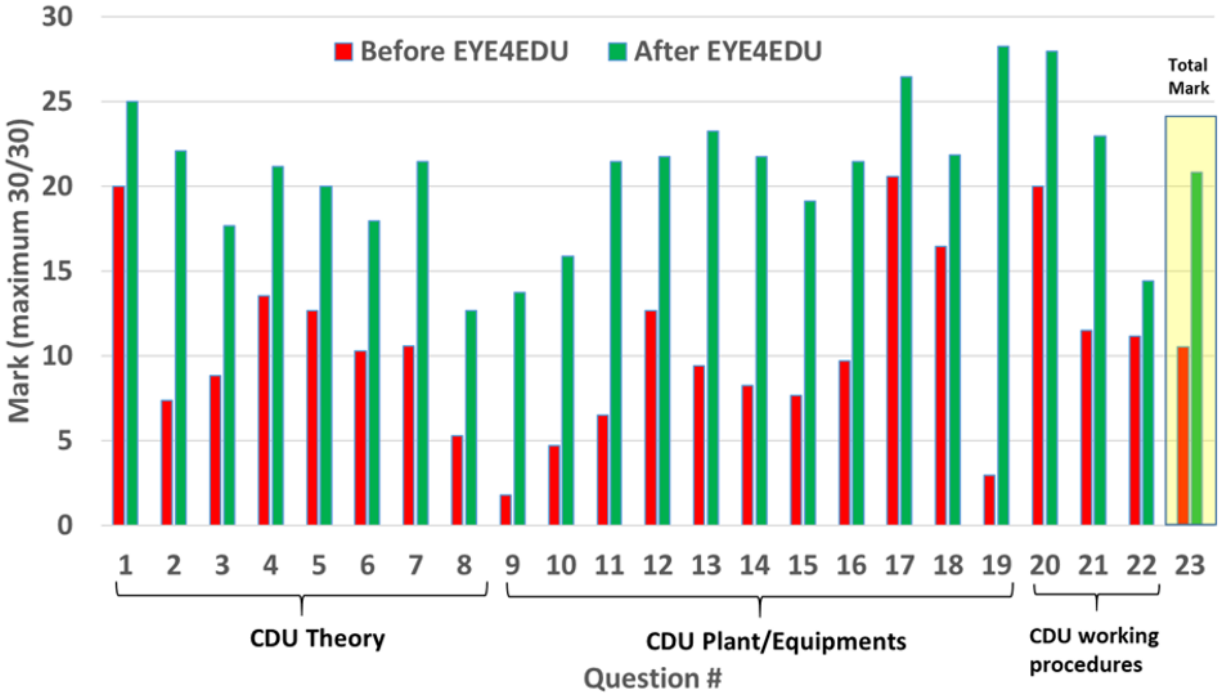

Figure 7: CDU test results before (red) and after (green) EYE4EDU exercise. Evaluation criteria: no answer: 0 points; insufficient answer: 10 points; sufficient answer: 20 points; excellent answer: 30 points.

It is easy to see the improvement of the answers quality after the EYE4EDU exercise. The total test evaluation before the virtual exercise was 10.5/30. The total test evaluation after the exercise was 20.8/30, then it was doubled. It Italy, sufficiency corresponds to 18/30.

The positive general trend is evident. The level of all the questions improves after the exercises in the VCDU. In particular, the level of the sections "CDU plant/equipment" and "CDU working procedures" increases more than that of the area "CDU theory". This result is the clear consequence that in the traditional lessons, it is very hard to explain the physical structure of chemical plants, the logistics and arrangement of the equipment and the operating protocols used in the plants. The learning of these topics requires different educational approaches. Traditionally, the students exit from university with very limited knowledge about these skills and only in the first years of professional work on the field they will acquire it. The possibility to provide visual context in real operating systems is always more difficult to students for cost and safety reason (Norton et al., 2008). Moreover, virtual representation of chemical plants can allow the exploration beyond traditional boundaries into equipment and operations, for example by inspecting the internal parts of unit operations or by observing them form several points of view that are impossible in real plants. In the VCDU the students can fly above the equipment or to observe them in points impossible in the reality for safety limitations.

The evaluation of the questions of the CDU theory results improved too after the EYE4EDU exercises. This result is connected with the improvement of the general knowledge of the plant acquired during the project. Several explanations, suggestions, clarifications were given to support the student before and during the development of the work. Moreover, an important part of the exercise was the reading and the discussion of the PFD and PID of the CDU plant. Also this work is possible only if the general understanding of the CDU plant is acquired by the students.

It is important to underlain that the aim of this part of the project was not a rigorous quantification of the educational impact of the activities, but only to obtain some qualitative but sound estimations of the potential impact of this new learning approach. The numbers reported in figure 7, in fact, are strongly dependent from the constraints assumed in the correction of the tests, as zero points for no answer, 10 for not sufficient answer, 20 for sufficient answer, 30 for excellent answer. Moreover, it is correct to consider that also by traditional lessons, with similar time for the activities, the learning of the student should improve, in particular for the theory section. Nevertheless, it is very important to combine the positive results of this qualitative evaluation and the positive results of the students' evaluation about this project, reported in the next paragraph. The conclusion should be that the students with EYE4EDU project improved their learning, by making activities that they willingly carry out with satisfaction and positive participation.

5. Students evaluation and learning

A final survey was proposed to the students, with general questions about the value and usefulness of the project. The list of the questions proposed in this survey, together with the number of selections, is reported in Table 4.

Table 4: List of the questions proposed in the EYE4EDU survey and number of students evaluations for each question (total number of students=34). Averages scores and their standard deviations were calculated by assuming: strongly disagree: 0; disagree: 1; neutral: 2; agree: 3; strongly agree: 4.

	Number of students selection					score	
Question	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Average value	Standard Deviation
Do you think that the EYE4EDU project was useful in general to improve your knowledge on the CDU?	0	0	0	15	19	3.55	0.49
Do you think the EYE4EDU project was useful to improve your knowledge on the theory of the CDU?	0	0	5	18	11	3.18	0.66
Do you think the EYE4EDU project was useful to improve your knowledge concerning the plant of the CDU?	0	0	1	7	26	3.74	0.5
Do you think that the EYE4EDU project was useful to improve your knowledge about chemical plants in general?	0	0	1	12	21	3.59	0.54
Do you think that the EYE4EDU project is a useful educational tool?	0	0	0	5	29	3.85	0.35
Do you think that virtual reality can give information and notions that are not able to offer traditional classroom lessons?	0	0	0	8	26	3.76	0.42
Do you think that virtual reality can give information and notions that are not able to offer traditional laboratory exercises?	0	0	4	8	22	3.53	0.42
Do you think that the combination of theoretical lessons, laboratory exercises and the use of virtual reality is the best educational method possible?	0	0	1	4	29	3.83	0.45
Do you think that the EYE4EDU project will be useful for your studies or for your future professional experiences?	0	1	3	22	8	3.09	0.65

Through the virtual experience, could you visualize and better understand the structure with which a chemical plant is built?	0	0	1	7	26	3.73	0.5
Through the virtual experience, have you been able to visualize and better understand how the various unitary operations studied in class (columns, pumps, heat exchangers, tanks etc.) are on a real scale?	0	0	1	7	26	3.73	0.5
Through the virtual experience, could you understand how the various working procedures in chemical plants are structured?	0	0	2	19	13	3.24	0.58

The survey results are also reported in figure 8.

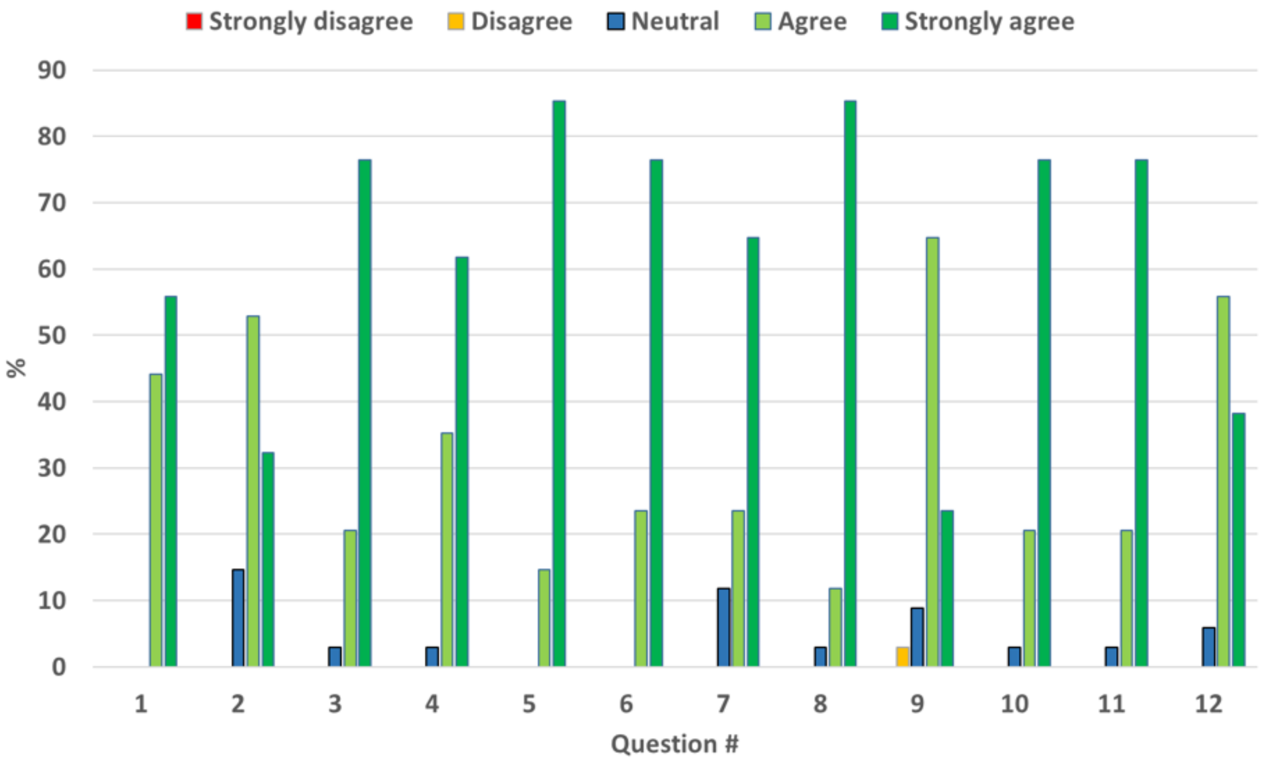

Fig. 8: EYE4EDU survey results, expressed as percentage of students evaluations.

The results of the survey are strongly positive in all the questions proposed to the students. To sum these results, a numerical value of 1 is given for all the answers "Strongly disagree", 2 for "Disagree", 3 for "neutral", 4 for "Agree" and 5 for "Strongly agree". The average final evaluation considering all the questions is 4.58/5. This means that for the students the virtual exercise in VCDU improved their knowledge in the chemical plants in general and they consider this project as useful for learning notions that are usually not learned by traditional lessons and/or laboratory exercises.

The students were also able to write free comments in the survey. The great majority of these were thanks or appreciation for the virtual exercise. Other comments have suggested speeding up some parts of the exercises, such as the slow opening of some valves, to increase the initial explanation of the VCDU plant and the creation of new exercises with greater freedom of execution by the operators.

6. Conclusions

EYE4EDU project was proposed to 34 students of the bachelor degree in the Industrial Chemistry in the University of Milan. Different kind of exercises, like the visit of the plant by reading the technical documents of the plant (PFD, PID) or some specific actions concerning the use of valves, pumps, units were proposed and explained to the students. The quantification of the learning impact was evaluated, from a qualitative point of view, by a specific test before and after the virtual exercises, in three different sections about CDU theory, CDU plant configuration and CDU plant working procedure. The level of all the questions improves after the exercises in the VCDU. In particular, the evaluation of the questions concerning the CDU plant/equipment and the CDU working procedures more than double. The results of the survey about student’s evaluation are strongly positive.

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