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Creation of Immersive Resources Based on Virtual Reality for Dissemination and Teaching in Chemical Engineering

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Abstract: Chemical Engineering is a complex discipline that is mainly applied to the industrial context, which makes it difficult to approach real equipment and systems in the classroom to students. Nevertheless, Information and Communication Technologies (ICTs) are particularly useful to encourage active and autonomous learning, normally associated with deeper levels of engagement and understanding of the subjects taught. In this way, several studies have demonstrated that immersion has the potential to increase learning experiences and improve creativity and engagement, Virtual Reality (VR) being a remarkable example. In this context, we created and shared with students two immersive resources based on VR: (a) a laboratory 360° video tour, which was used to disseminate the Chemical Engineering Degree in an Open Door Days organized for high school students; and (b) an experiential learning tool integrated with Moodle, which was available previously to face-to-face practical lessons of the subject Separation Operations. In both cases, the feedback from the participant students was positive. High school students increased their interest in Chemical Engineering Degree after viewing the 360° video, meanwhile undergraduate students found the immersive tool useful in the subsequent performance of real practical activities. From the perspective of professors, creation of these resources required purchase of equipment, time and effort, but they were highly valued as a tool for disseminating and supporting teaching, being an initial starting point for the creation of more enhanced VR-based materials.

Keywords: chemical engineering; immersion; virtual reality; 360° videos; laboratory practices

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1. Introduction

Chemical Engineering is one of the broadest of the engineering fields, focused on developing processes and industries for manufacturing chemicals and compounds. Therefore, it is a highly complex discipline that is mainly applied to the industrial context [1,2], which makes it difficult to approach real equipment and systems in the classroom to students of the degree in Chemical Engineering [3]. Recently, with the increasing advances in technology and the COVID-19 pandemic, Information and Communication Technologies (ICTs) are being widely applied for teaching and for learning purposes [4–6], because digital resources are particularly useful to encourage active and autonomous learning, normally associated with deeper levels of engagement and understanding of the subjects taught [7]. Remarkable examples of digital resources include Virtual Reality (VR), Augmented Reality (AR), or Mixed Reality (MR) [8–11], which are promising at helping students to improve their visualization skills in complex subjects, the majority being in application to Chemical Education [12]. Specifically, VR is a 3D environment in which a user can look around, navigate, and/or interact with virtual objects in an almost natural way [13]. Taking the advantage of this full immersion, VR educational applications have been proliferating in recent years [12] and, consequently, they have been steadily gaining momentum in Science, Technology, Engineering, and Math (STEM) education. Thus, researchers, educators, and industry practitioners tend to design and develop more and more resources that promote experiential and active learning, as opposed to the traditional teacher-centered (passive) approach [14,15]. Thereby, numerous studies have demonstrated that immersion has the potential to increase learning experiences [16] and improve creativity and engagement [17]. Consequently, an appropriate use of ICTs involves pedagogically and user-oriented practices to satisfy students' expectations, potential needs, and increase their participation. These requirements can make the development of learning tools time consuming and be demanding in terms of multi-disciplinary knowledge required [18].

In the context of the development of an immersive environment, 360° media play a key role due to the fact that they offer 360° panoramic images and videos, which can be viewed using a smartphone (via specialized viewer app or via online platforms). Nowadays, there are two main ways to view and navigate 360° media via mobile phone. First, while the video is playing, the viewer can hold their phone up in the air and move it laterally and vertically. Secondly, the viewer can insert the phone into a VR Head-Mounted-Display (HMD), previously activating the VR viewing option on the phone. In this study, we opted for the second way (phone into HMD), given the greater degree of immersion of the viewer, due to a unique image per eye invoking stereoscopic depth perception [19].

In a pedagogical context, the use of VR videos has a number of benefits, from teachers' and students' perspectives [20]. Thus, VR allows students to move to virtual environments and view VR 360° videos which would hardly be shown with traditional teaching resources. Further, following the novelty and excitement that arises, it may, thereby, generate higher viewer engagement and focus. In addition, mastering these tools in any of the curricular areas of the degrees would facilitate the design of spectacular activities by incorporating, or linking, these interactive materials on the same support materials already used in classes. Finally, the production of virtual laboratory resources, such as tour, training, or skill development, videos is very affordable in terms of staff time and production costs.

Additionally, 360° videos present technical recording benefits compared to conventional recording. Usually, with the 360° camera, one typically does not need to worry if a part of the demonstration is out of the scope of view in the camera frame due to the 360° panoramic field of view is able to capture laboratory procedures without continually moving the camera around. Moreover, the use of 360° cameras would be advantageous because it is independent of an additional camera operator and can be performed solely by the lab instructor [21].

On the other hand, the drawbacks of 360° videos include simulation sickness, induced by the shaky movements produced when viewing and navigating around the videos. Fortunately, this discomfort can be reduced by mounting the 360° camera at a fixed position or would be resolved by holding the mobile device with both hands or placing the device on a flat surface during viewing. Another potential problem is the loss of focus in 360° videos, that is, the difficulty in finding the right angle of the video at the right time. Improving on this loss of focus is challenging and requires further work. Some studies have reported a remedy by creating a time delay to provide buffer time for the viewer to reorientate themselves at pivotal time points in the video, e.g., when a demonstrator is conducting a critical step in an experimental procedure [22].

In the framework of this work, we started by searching for open access resources of immersive experiences related to Chemical Engineering, in order to just provide them to the students. Thus, an exhaustive search for available resources or applications of VR, AR, 360° videos, etc., was carried out on the internet, research papers in education and educational projects at other universities. Regrettably, no specific resources on chemical engineering processes were found that suited our teaching purposes. Only some VR and AR specific applications in chemistry were found, and scarce 360° videos of production plants were located [4,21,23].

Hence, we generate immersive resources based on VR with two objectives. First, 360° virtual tour videos (360VTVs) of the laboratories used in teaching and researching in Chemical Engineering subjects were created, in order to disseminate the interest in this discipline to the public. Secondly, an experiential learning tool (ELT) was created, in order to prepare and help the undergraduate students beforehand and complementary to real practical lessons. In addition, this work shows the opinion of students and professors about the developed 360VTV and ELT resources. Thus, in all cases, professors and students who participated in the VR activities were asked to answer a post-survey to collect their feedback in order to assess the VR activities carried out.

Therefore, in the following sections the recording and viewing equipment used are described, as well as the types of recordings and immersive resources based on VR created. Finally, their usefulness is shown and discussed through evaluation and feedback from the participants.

2. Materials and Methods

In this section, the recording and visualization equipment used is described. Moreover, details of the immersive resources created, 360VTV and ELT, are explained. Finally, the process of collecting feedback from the participants is described and the questionnaires included in post-surveys are shown.

2.1. 360° Videos Recording Equipment

Before the selection of the equipment, various alternatives were evaluated through the guidance provided by the Digital Resource Centre of the University of Cádiz. Finally, the videos were produced using a 360° camera One X® (see Figure 1a). This cam was mounted over different stands during recordings depending on requirements. Thus, for ELT, several static 360° videos were recorded mounting the camera on a tripod stand (see Figure 1b) and the operator recording using the fixed camera. However, for 360VTVs, we used the extended selfie stick stand (see Figure 1c) as a rig to hold (see Figure 2a) and rotating the camera during recording (see Figure 2b).

(**a**) (**b**) (**c**)

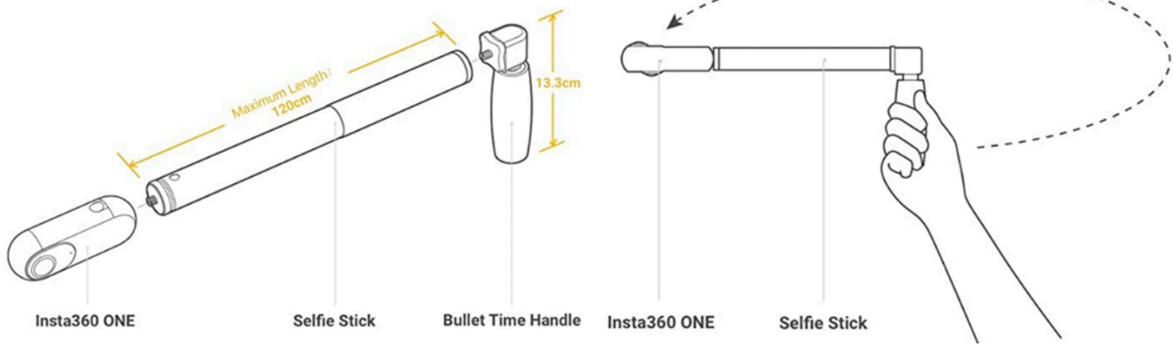
Figure 1. (**a**) 360° camera One X®; (**b**) Tripod stand; (**c**) Extended selfie stick.

After recording, the videos were subsequently annotated using a video editor (INSTA360 STUDIO2021) and injected with 360° spatial metadata. The edited videos were then published in public YouTube® platform that support 360° viewing.

For the handling of the recording equipment, as well as for the editing and generation of the videos, support was provided by the Digital Resource Centre of the University of Cádiz.

2.2. Virtual HMD

We purchased a Virtual Reality Head-Mounted-Display (VR HMD) for showing to students the 360° videos generated. Considering the different options available on the market we opted for an operation way in which the viewer inserts the smartphone into a HMD, previously activating the VR viewing option on the phone. Specifically, we purchased the virtual HMD SHINECON 3D (Figure 3) suitable for smartphones and other mobile devices with 4″–6.7″ displays.



(a) (b)

Figure 2. (**a**) Extended selfie stick specifications; (**b**) Rotation with the extended selfie.

Figure 3. Virtual HMD mode purchased.

2.3. Creation 360VTVs

Two different 360° videos were realized. In the first kind of 360° videos, tour videos were recorded with the purpose of promoting and showing the laboratories used in the teaching of the Degree and Master in Chemical Engineering at the Faculty of Science (University of Cádiz, Cádiz, Spain). In the second kind of 360° videos, a static video was recorded with a demonstration of a laboratory practice of the Chemical Engineering area.

Regarding the tour videos, first, we proceeded to record a video tour of the pilot plant and teaching laboratories, during the routine of the practical sessions carried out by the students and professors. To make this video more impressive, a drone provided by Drones Service of the University of Cádiz was used. Hence, in the initial part of the video we show, for a few seconds, the aerial view and location of the Faculty of Sciences within the Campus of Puerto Real (University of Cádiz, Cádiz, Spain), which is located in a privileged natural environment, in the Natural Park of the Bay of Cádiz. Figure 4 shows some photograms of the 360° video recorded.

The following link shows the resource generated (it can be seen in 360°): https://youtu.be/2DG6-YO4uKQ, (accessed on 18 August 2022).

Moreover, other videos were recorded in the research laboratory of two research groups: the one named Analysis and Design of Supercritical Fluid Processes and the one named Biological and Enzymatic Reactors, both in the Chemical Engineering and Food Technology Department. Figure 5 shows some photograms of the 360° video recorded.

The following link shows the resource generated (it can be seen in 360°) recorded: https://www.youtube.com/watch?v=Cvrq9nt5s_w, (accessed on 18 August 2022).

Particularly, we share these 360VTV in the Open Doors Day (University Orientation Days, University of Cádiz, course 21/22). This annual event is organized with the purpose of disseminating and promoting the degrees among the students from different high schools in the area, and with the interest to enroll in any of the disciplines offered at the University. In particular, those students potentially interested in Chemical Engineering passed by a stand where a professor of the degree explained different aspects of the discipline and the possibility of carrying out a VR activity. In this activity they could watch a video that allowed them to know the facilities and operations that are used during the practical lessons of the Degree in Chemical Engineering. Subsequently, students interested in this activity went to a second desk where they were given VR HDMs and basic instructions on how to use the device with their personal smartphone, together with the quick response (QR) code of the video (linked to YouTube® platform).

Figure 4. Different photograms of the 360VTV.

Regarding to the second kind of 360° video generated, static video in a practice laboratory, the professor recorded himself carrying out the practical activity and explaining the methodology step by step, following the same procedure and instruments that are then proposed to the students during the face-to-face lessons. Figure 6 shows an example of some screenshots of such videos corresponding to the four practical activities recorded: sedimentation, distillation, liquid–liquid extraction, and solid–liquid extraction.

The following link shows the resources generated for this type of 360° video: https://www.youtube.com/playlist?list=PLYVlAYnhsZHqYUL7mXffSj3u84t8ymshn, (accessed on 18 August 2022).

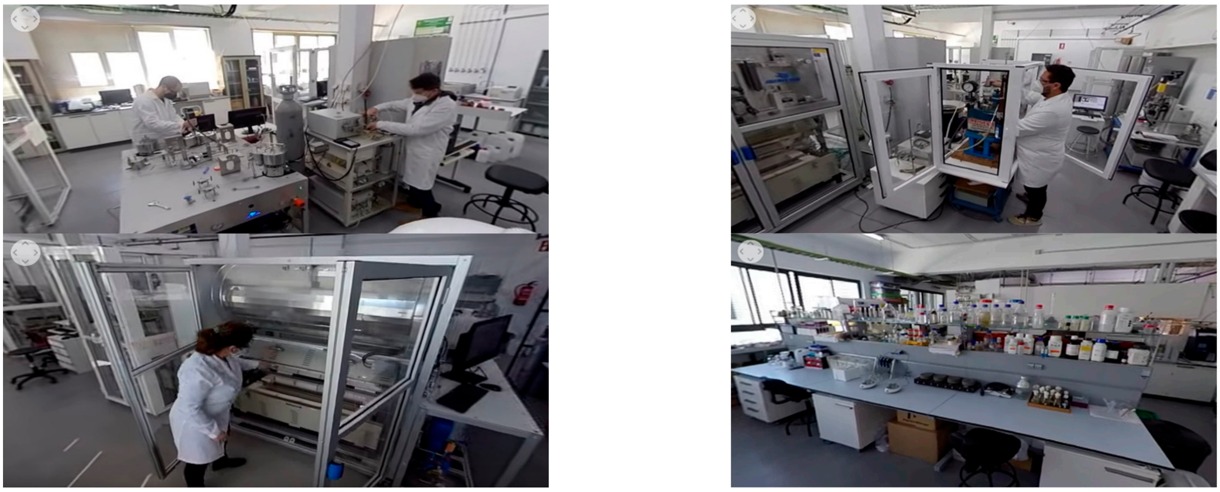
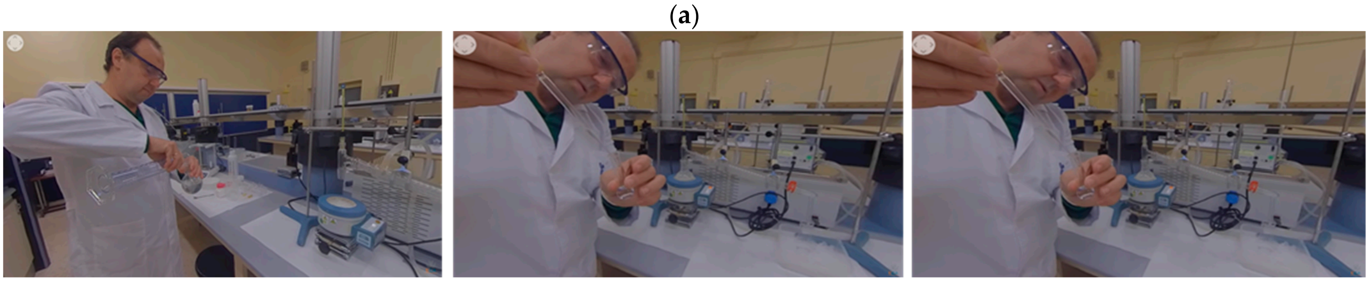


Figure 5. Different photograms of the 360° video of the laboratory research.

(**a**)



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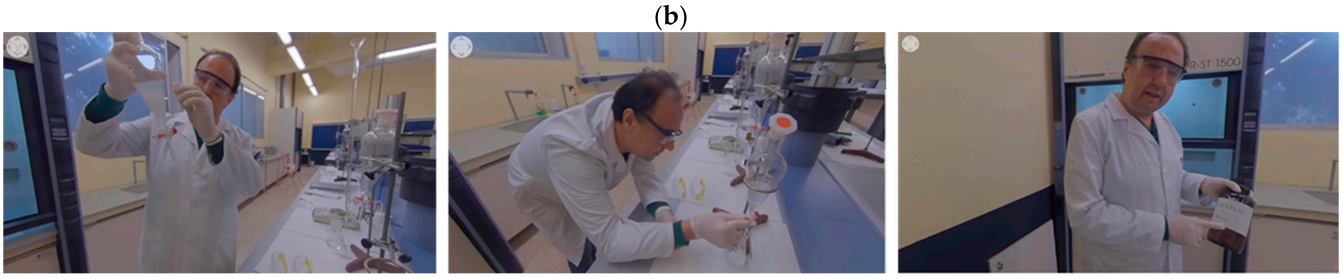

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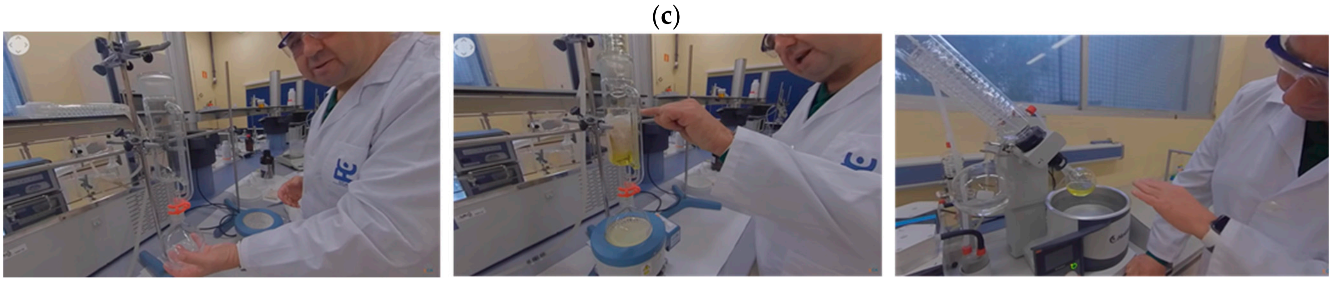

(**d**)

Figure 6. Screenshots of the four practical 360° video recorded. (**a**) Sedimentation; (**b**) Distillation; (**c**) Liquid–liquid extraction; (**d**) Solid–liquid extraction.

2.4. Experiential Learning Tool (ELT) Based on VR

The subject selected for developing this tool was Separation Operations, corresponding to the third course of the Degree in Biotechnology (Course 20/21), which is taught by professors of the Chemical Engineering Area. An interface was developed using all-in-one screen recorder, video editor and eLearning authoring software, named ActivePresenter of Atomi Systems (https://atomisystems.com/activepresenter/) (accessed on 18 August 2022).

Subsequently professors adapted the interface developed and integrated it into Massive Online Open Course (MOOC) commonly used in the subject, Moodle 3.6, via Shareable Content Object Reference Model (SCORM).

An ELT was created for each laboratory activity that the students carry out during real practical lessons of the Separation Operations subject: sedimentation, distillation, liquid–liquid extraction and solid–liquid extraction. Specifically, the ELT was composed of four main components or sections, which were depicted in the homepage, as shown in Figure 7: theoretical explanation, video of the practice, simulation and 360° VR.

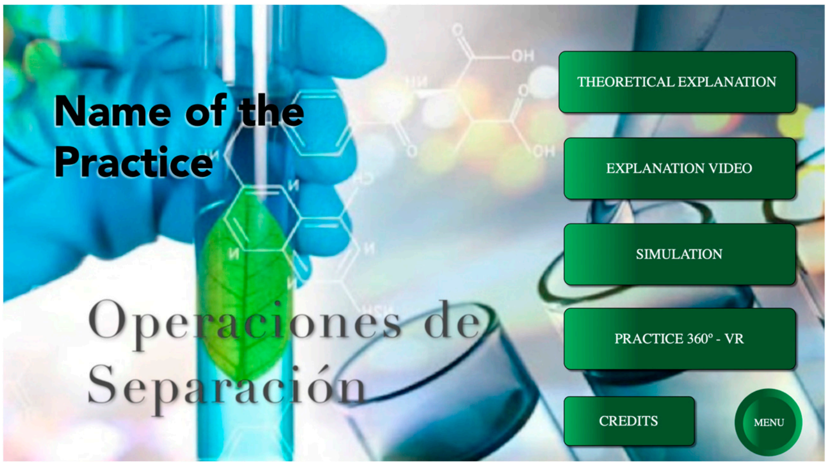

Figure 7. Homepage of the ELT developed for each activity.

From this homepage, the student could freely navigate through and access any of the four components. The theoretical explanation component contained slideshows with the key concepts involved. The video practice section contained a brief explanation of the professor about fundamentals of the activity (3–5 min approximately). The simulation component included a recreation, in which, an assistant represented by an animation of the professor guides the student step by step through the whole experimental procedure to be carried out, with different images and videos of the material and equipment used the images include a laboratory material checklist and all real numerical data needed for calculations and to obtain the final results requested. Finally, the 360° VR section includes a video, where the professor carries out and explains the practical activity by himself as a described in section above. Appendix A shows several screenshots as an example of all these components.

Once the material is created, undergraduate students had individual access to the ELT through the MOOC of the subject in advance of the real practical sessions, which were carried out in pairs of students in the conventional way, i.e., face-to-face lessons.

2.5. Students and Professors Feedback: Surveys

To assess the VR activities developed, surveys for participants in this study (students and professors) were conducted. For the elaboration of all surveys, questionnaires used by other studies in the evaluation of resources based on VR in STEM disciplines similar to Chemical Engineering were taken as a guide (Biotechnology, Bioprocess and Biochemical Engineering, among others) [23,24]. In addition, a group of professors with extensive teaching experience in Chemical Engineering Area involved in the development of this work, participated in the elaboration of the questions, which were discussed and selected before being presented to the participants. Thus, students, once they had finished viewing the VR activities, 360VTV or ELT, gave their consent to participate in this study and were invited anonymously to answer a survey, in which they are asked about their impressions of the VR resources shown in terms of usefulness, satisfaction, and motivation, among others. As presented in Tables 1 and 2, specific questions were designed for each VR activity with the aim of determining the usefulness of the resources generated as a pedagogical tool and their rating, as well as identifying aspects that could be improved. In all of them, the different types of questions were mixed, and they contemplated various types of answers, such as open-ended, closed-ended, yes/no and rating questions with 5 point-likert level scale. Complementarily, at the end of the questionnaires, the students were asked to voluntarily write any other comments they would like to include freely. In the case of 360VTV, the post-survey was provided on paper, while in the case of ELT, the MOOC was used to host it.

Table 1. List of questions proposed in the post-survey about the 360VTV.

No.	Question	Type
1	Gender	Closed-ended
2	What is your locality?	Open-ended
3	What is your subject pathway in the High School?	Open-ended
4	Have you ever used VR glasses?	Yes/No
5	If the answer to the previous question is YES, please indicate the context in which you have used them	Open-ended
6	If you have used VR glasses before, please indicate the level of satisfaction with your previous experience	5 point Likert-scale
7	Why were you interested in this activity?	Close-ended
8	Did you like the 360VTV shown?	Yes/No
9	Rate the quality of the video shown	5 point Likert-scale
10	Rate the quality of the sound	5 point Likert-scale
11	Would you have liked the videos to have included a narrator's voice to explain what was being shown?	Yes/No
12	Would you like to see more VR videos like this related to other Degrees taught in the Faculty of Science?	Yes/No
13	After watching the video, has your interest in the Degree in Chemical Engineering increased?	Yes/No
14	Rate overall your experience during the activity 360VTV	5 point Likert-scale
15	Box to comment on any aspect of your experience in this activity that we have not included in this questionnaire	Open-question

Table 2. List of questions proposed in the post-survey about ELT based on VR.

No.	Statements	Type
1	Rating as a teaching tool	5 point Likert-scale
2	Rating as an explanation the experimental procedure	
3	Rating as a simulator of laboratory practice lessons	
4	Overall rating	
5	Most difficulty experienced when watching the videos	Open-ended
6	Point the most valuable thing about the ELT	
7	Indicate things that could be improved in the ELT	

Furthermore, professors from the Chemical Engineering Area involved in the development of this work were invited to answer a survey to know their opinion with the aim to determine their point of view about the VR resources generated in terms of usefulness, improvement and global valuation (Table 3).

Table 3. Professor survey statements about VR resources generated.

No.	Statements	Type
1	Useful for fostering self-learning of student	5 point Likert-scale
2	Useful to understand some parts of the equipment	
3	Useful to better remember concepts	
4	Useful for enhancing students motivation	
5	I think that in some sections of the subjects related to my teaching it would be interesting to carry out this initiative	
6	It would be great to use VR in the orientation days related to the High School and/or Master.	
7	It is an excellent tool to support teaching, dissemination or diffusion.	
8	It's fine as a curiosity, but it's not useful for anything else.	

Table 4 shows details of the number, formation of the participants and the resource they were surveyed about.

Table 4. Details of the participants surveyed.

Formation	No.	Survey about
High school students	148	360VTV
Undergraduate Biotechnology students	20	ELT
Professors of Chemical Engineering Area	10	360VTV & ELT

Finally, the data and answers collected of the post-surveys were analyzed using the software Microsoft® Excel® 2016.

3. Results

In addition to the materials generated, 360VTV and ELT, the main results of this work can be found in the analysis of the responses obtain to post-surveys carried out with the participants after the end of their VR experience. Use of the surveys is one of the methods described and commonly used for the collection of information in VR technology in chemistry and in learning analytics of STEM subject practices in terms of gender, usability, motivation, and attitude, among others [25].

3.1. 360VTV

As shown in Figure 8, during Open Door Days celebrated at Faculty of Science (Orientation Days, University of Cádiz, course 21/22,), high school students interested in Chemical Engineering Degree spent several minutes (from 3 to 5 min) watching the 360VTV with the virtual HMDs provided. They were accompanied at all times by professors of the Degree in Chemical Engineering who provided support and additional explanations about the video. Once they had finished the viewing, the participants students (n = 148), were invited to answer the suggested survey (Table 2). The main results obtained are detailed below.

In order to find out about the students interested in participating in this activity on the Chemical Engineering Degree, they were first asked about their gender and the subject pathway they were studying at the High School. The majority of the participants were women with a total of 61% and students of Science/Technology and Health subjects. Table 5 summarizes the detailed answers about the subject pathway of the students that participated in this activity.

Nowadays, VR tools are becoming increasingly present in our daily lives; hence, we found it interesting to know if the high school students had previous experience and what their level of satisfaction. The result to this question was 60% had already used this type of VR tool, mainly in leisure, videogames, and films, as shown in Figure 9. Moreover, 71% of students had already had a positive (4 out of 5) or very positive (5 out of 5) experience in a proposed Likert scale evaluation (see Figure 10).

Figure 8. High school students and professors during the VR activity.

Table 5. Subject pathway high school of the students interested in 360VTV on Chemical Engineering.

Pathway	Answers	%
Science/Technology	54	36.5
Health	53	35.8
Social	26	17.6
Humanities	5	3.4
Unknown	10	6.8
Total	148	100.0

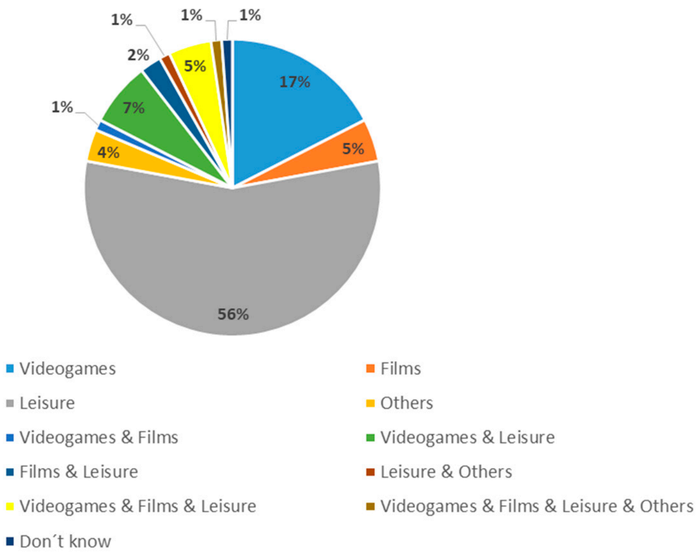

Figure 9. Results of previous experiences with VR.

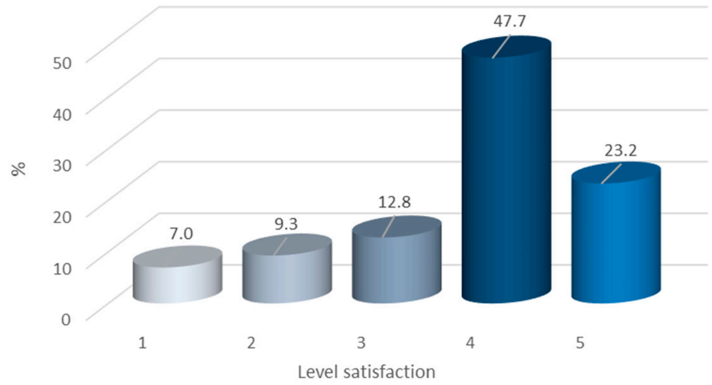

Figure 10. Percentage of the level satisfaction of high school students in previous experiences VR.

Moreover, students were asked about the main reason that motivated them to watch the VR video proposed in this Chemical Engineering activity, to choose among multiple options given. Thus, as shown in Figure 11, 38% of them were interested by the fact that the video was related to VR activity, followed by 32% who were interested by the information previously provided at the stand. It is remarkable that 22% of the students surveyed came to watch this video due to their previous intention to enroll in the Degree in Chemical Engineering.

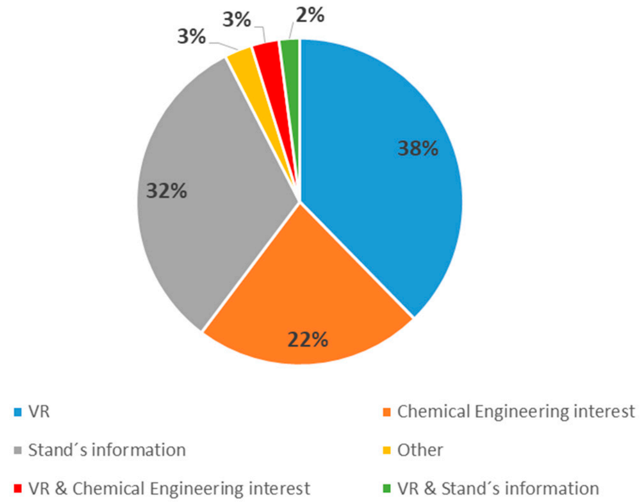

Figure 11. Previous motivation in taking part in the proposed VR activity.

Focusing on the questions specifically related to the VR video shown, the response to the yes/no question was unanimously positive when asked if they liked the 360VTV, with 99% of the students answering affirmatively. Moreover, they were asked to rate the quality of the image and sound of the video rating a 5 point Likert-scale, as well as an overall assessment of the VR experience. Figure 12 shows the average results of these ratings, where it can be seen that the lowest score, 3.5, was for sound rating, while for the other evaluations the average was close to 4 or higher.

As a complementary element for improvement, the students were queried if, during the viewing, they would have preferred hearing an off-voice with an explanation (narrator). The answer was 86% affirmative.

On the other hand, it should be noted that one of the main targets set of this activity was the promotion and enthusiasm of this degree among high school students, finding that 70% of those surveyed after the viewing of the 360VTV increased their interest in the discipline of Chemical Engineering. Furthermore, 98% indicated that they would like to see more VR videos related to other degrees currently offered at the Faculty of Science, such as Chemistry, Biotechnology and Enology.

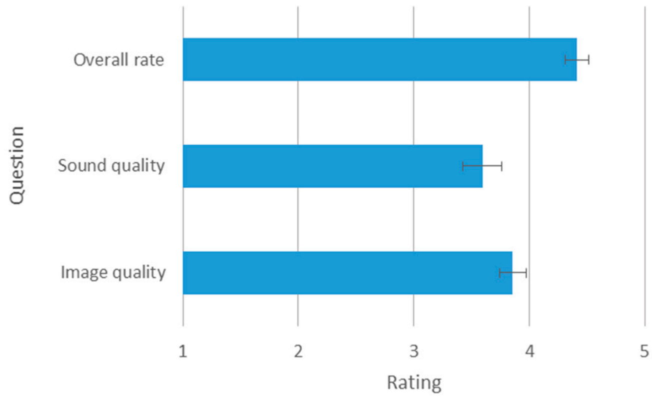

Figure 12. Average of responses of rating scale. Error bars show 95% confidence interval.

Finally, we collected student feedback, not only with 5 point Likert-scale or closed questions, but also in the form of freely comments with respect to their experience of visualization of 360VTV with HMDs. From this feedback garnered seven responses, represented just 5% of the participants, being majority very positive. The comments were as follows:

#1. "The experience was amazing and I found the 360° VR mode very interesting"
#2. "A very fascinating activity"
#3. "I liked it"
#4. "Thanks"
#5. "It was great but I would have liked more diversity and dynamism"
#6. "Very good feeling and I found it interesting although the vision was a bit blurred"
#7. "Very helpful professors and interesting experience"

3.2. ELT Based on VR

Undergraduates enrolled in Separation Operations subject were able to access individually and previously to the start of the practical lessons to the ELT developed through the MOOC. Afterwards, the students carried out the real practical lessons in groups of pairs, following the established routines in face-to-face.

Several advantages of virtual platforms were found in the ELT created that have been previously reported by other studies [26–28]. In this way, students could be able to develop practical laboratory skills by taking advantage of information gathered in ELT. Additionally, an important feature of virtual laboratories is that the learning process can be simplified by highlighting relevant information and avoiding confusing details. Moreover, it is well known that a virtual platform like this also makes the interpretation of certain phenomena easier and collect information or results during shorter time frame as it would take to do in the real experiment.

Once students finished these real laboratory practical lessons, they voluntarily answered a post-survey with the questions included in Table 2. The questions designed for this questionnaire can be divided in two types. On the one hand, students were asked to rate on a 5 point Likert-scale of diverse statements with the purpose to find out the usefulness of ELT generated (see Table 2, statements 1 to 4). The average of responses corresponding are represented in Figure 13 and all ratings were 5 or very close to 5, which mean that students found very helpful this tool.

On the other hand, the second part of the survey was an open-ended set of questions where participants were asked to indicate freely personal aspects of difficulty, assessment and improvement detected during their experience with ELT (see Table 2, statements 5 to 7). Thus, most of them did not find any difficulties. Only two of them indicated problems with the audio. In addition, none of the participants indicated any possible improvements. Finally, in reference to what they most valued about the ELT developed, the students highlighted and congratulated the work of the professors who made the development of this tool possible through comments where the most repeated words were: great work, enormous effort, and great dedication by the professors. These positive comments represented 56% of the total number of students surveyed, while the rest left no comments on this box.

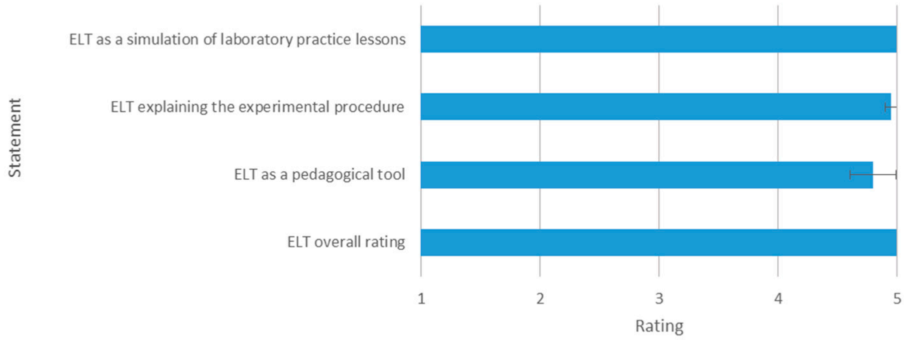

Figure 13. Average of responses of rating scale. Error bars show 95% confidence interval.

3.3. Professors Feedback

The feedback collected from the professors involved in this study through the post-survey provided are summarized in Figures 14 and 15. On the one hand, Figure 14 illustrates the degree of agreement or disagreement of the professors with particular statements related to the perception of 360VTV generated. As shown, the perception was very positive due to 100% of the professors surveyed strongly disagreed that the VR resources were of no use. In addition, 85% strongly agreed to use these materials, specifically for Open Doors Day concerning to High Schools or Master's programs. Consequently, this massive response led to the 360VTV being offered to high school students at the University Orientation Days during the 21/22 academic year. Additionally, none of the professors agreed with the idea of not implementing VR resources in any part of their subjects, with 43% of the professors agreeing and 57% strongly agreeing with this statement.

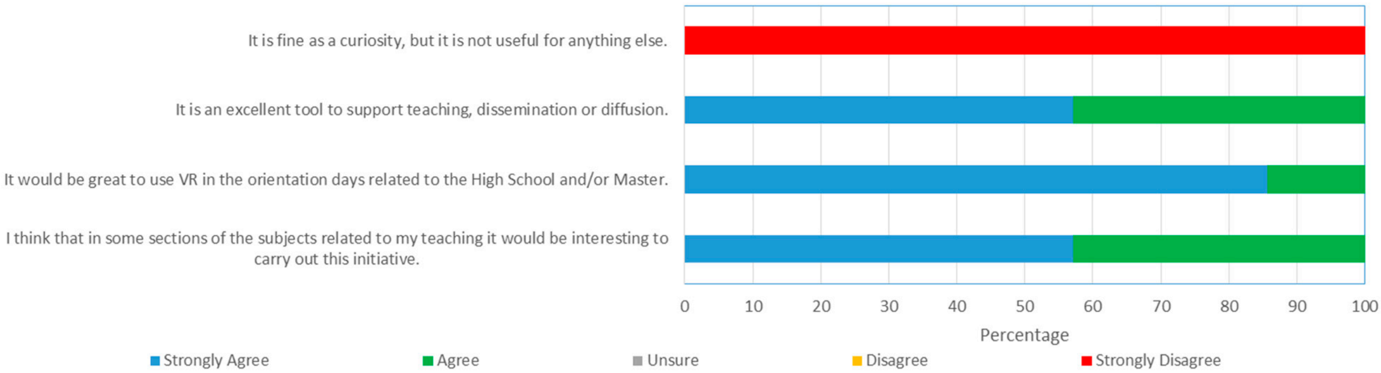

Figure 14. Average of responses of professors about 360VTV. Error bars show 95% confidence interval.

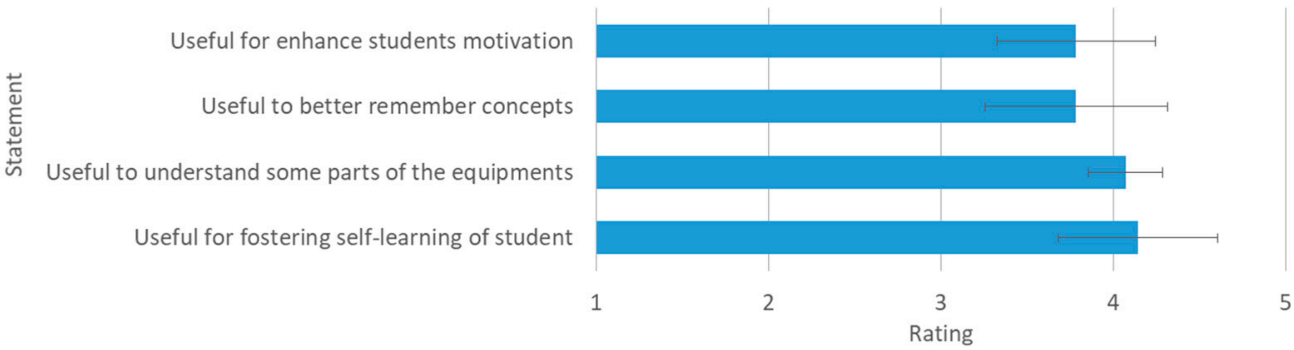

Figure 15. Average of responses of rating scale. Error bars show 95% confidence interval.

On the other hand, Figure 15 shows the average responses about those statements related to the usefulness of the VR as a supporting tool in the learning of the subjects. This way, the evaluation was positive in all cases, obtaining the highest score (above 4) in the assessment as a tool for self-learning and to improve the understanding of parts of equipment. The rating was slightly lower at 3.8, on those issues related to the usefulness of enhancing the motivation of students and the retention of certain concepts.

4. Discussion

In order to know the impact and usefulness of the different VR resources generated the main results are discussed in the following subsections.

4.1. 360VTV

It is often difficult to promote and disseminate Chemical Engineering Degree at University open doors days due to physical barriers of moving huge and delicate equipment and measure instruments from the pilot plant and teaching laboratories to the venue. Real tours play an important and irreplaceable role in providing students with Chemical Engineering process and operations observation. Nevertheless, although there is the possibility for participants in this event, to take a real guided tour of the Chemical Engineering pilot plant and teaching laboratories, they will never have the opportunity to see the equipment in operation due to safety reasons and the large number of participants, among others. Thus, the viewing of these 360VTV was a great opportunity for the high schools' students to see and embed in 360° perspective the pilot plant and the laboratories during the routine practical lessons with undergraduate and professors. These same strengths have also been found by other studies related to virtual field visits in Chemical Engineering discipline [24]. Consequently, the 360VTV were viewed by 148 high school students interested in the degree in Chemical Engineering, of which 61% were women. That female majority is in agreement with female interest in STEM (science, technology, engineering, and mathematics) careers during the high school years even though they are ultimately underrepresented in these professions [29]. In addition, more than 70% of the participating students (men or women) were studying Health or Science/Technology pathways in the High School (see Table 5), what seems reasonable due the interest demonstrated by them in doing an engineering and science activity, like as proposed.

Based on the responses collected, 60% of participating students had already had previous experiences with VR activities, mostly related to leisure activities or video games (see Figure 9), which in their opinion were positive, with 71% rating them as good or very good (see Figure 10). This high percentage is according to the fact that VR is increasingly present in our daily lives [30]. Moreover, this result clearly indicates that the target audience for this activity had a high perception of this type of applications, which gives further value to the results that 98% indicated that they liked the video and their positive overall rating with a 4.4 out of 5 (see Figure 12). This positive feedback is in line with several studies that received positive responses from students with regard to these virtual field visits in diverse disciplines including chemistry [31–33] and environmental sciences [34,35].

Another aspect to note is the increase of interest in Chemical Engineering after this activity among the participants; 22% of them stated that their main motivation for participating in this VR activity was due to their intention to enroll in the Degree in Chemical Engineering (Figure 11). Meanwhile, 70% of the participants answered that after viewing the 360VTV they were interested in Chemical Engineering.

Answers from question 11 (*Would you have liked the videos to have included a narrator's voice to explain what was being shown?*) suggested that improvement should be added for better understanding of the process and equipment shown, with an 86% of affirmative responses. Other studies that have produced 360VTV [36] suggest improvements in this direction but interactive elements, such as including embedded videos or slideshows of the processes being conducted in the different places of the laboratory. This way, the student could know and get more information around the laboratory setting as they activate the action points shown in remarkable places (hotspots), such as certain operations or safety equipment. In this line, recent advances show that it is feasible to enable interactive features and allow the user to interact in the virtual environment through hotspots with the support of platforms, such as VIAR360. This aspect is considered as point for improvement by the authors in upcoming versions of the 360VTV. Additionally, as a future line of work, there are other possibilities to interact with some content shown, such as 3D models that can be manipulated with hand gestures or controllers [37], or even the development of mini-labs based on VR, where students could conduct their experiences prior to their practical lessons [24,38,39]. Furthermore, all this could be evaluated with two different groups of students (with or without access to the generated immersive resources) in order to determine the level of competence achieved by each group.

Furthermore, note that it could be of interest to generate similar resources to the 360VLT created for the Chemical Engineering Degree, but in other disciplines, such as Chemistry, Biotechnology or Enology. This fact is supported by the results collected of question 12 indicated that almost all participants (98%) were in agreement with generating and promoting more 360VTVs for other degrees taught in Faculty of Sciences.

Although it did not occur during the development of this activity, it should be noted that the main drawback found in other studies is that the use of virtual reality devices such as HMD could cause physical discomfort including cyber sickness, nausea, headache, and eye strain to the users [40,41]. This might also distract the users and could negatively impact the immersive pedagogical experience.

4.2. Experiential Learning Tool (ELT) Based on VR

According to Norton et al. [42] principles of instructional design of educational multimedia were followed for the development of ELT created. Principles such as multiple representation, contiguity, coherence, spatial contiguity, personalization, and self-referential effect were included in four components of ELT. It is important to highlight that during the ELT creative process, similar difficulties described by Viitaharju et al. [43] in their study on AALTOLAB for laboratory were encountered, such as more development of the VR resources, shooting and editing videos take time, and lack of personal contact with students and professors. Furthermore, according to description of different types of experiments and corresponding learning outcomes described by Bhute et al. [4], the ELT designed corresponds with type B, which is defined as experiential, where equipment is used for experiment, but not the main objective of the experiments, the main objective being the understanding and fundamentals of the proposed separation operations.

The findings from the VR-supported educational activities are well-documented by a substantial body of literature as are the benefits that this technology brings to the learning process, such as student-centered, self-directed, and self-regulated learning [26]. Hence, ELTs were provided to the students in advance of the real practical sessions through MOOCs of the subject, emphasizing in their contents designed the most important aspects in order to facilitate the understanding of the instrumentation and procedure to be followed during the development of the practical sessions. This fact is key because, in this way, students can take advantages of laboratory experiments. Other studies reported this benefit, which highlights that watching virtual experiments is one of the approaches that provides pre-knowledge on the topic in terms of fundamentals, methodology, preparation, and execution [24,43]. From the perspective of students, one of the advantages of ELT is that they can study and learn at their own pace, when they have time to do it and in an autonomous way. However, to enable independent studying, the study material needs to be carefully designed.

As shown in Figure 13, students unanimously strongly agreed on the ELT generated due to finding this resource useful as a simulation, pedagogical, and explanation tool. This supports the use of the ELTs generated in this study as a library of immersive VR environments and an interface to serve as a template to generate more ELTs with other chemical engineering experiences used in practical laboratory lessons of other subjects, such as Reynolds and Bernoulli experiences, fluidization, or heat transfer, among others.

In contrast, there are certain drawbacks associated with this ELT created, discussed as follows. Obviously, students cannot acquire the required skills needed to execute accurate experiments in the laboratory which they will acquire subsequently during the irreplaceable face-to-face laboratory practical lessons. Another relevant issue to validate this tool is the small sample size (20 participants), which represents a limitation of our research due to the voluntary character of the post-survey. In this sense, these ELTs will be integrated in the next academic courses through of MOOC subject, being available for more undergraduate students. Other problem is the impossibility to answer the doubts the students during their experience. Consequently, it could be interesting to incorporate a test with questions related to student learning during the VR experience shown in the ELT, taking advantage of integrating with a MOOC-based digital test with automatic assessment. In this way, it would be possible to evaluate the degree of student understanding derived from this VR resource. Similar experiences have been reported for other studies, where the authors developed a digital laboratory safety training [44].

4.3. Professors Feedback

In the sample of 10 professors who participated in the evaluation and assessment, there were different academic ranks, consisting of professors, full professors, and associate and substitute professors, with teaching experience ranging from less than 5 to more than 30 years. Consequently, in the discussion of the results obtained in the surveys of the professors, it should be noted that their assessment of the resources generated may be more severe than that of the students due to their higher knowledge of the equipment and processes. Therefore, the average rating of around 4 in different aspects can be considered positive, indicating its usefulness as an element of pedagogical support (see Figure 15), taking into account that it is the first VR resources generated by the Chemical Engineering area. In any case, all the possible improvements described in the previous sections have been detected by the professors and will be taken into account in the development of future VR improved resources. It should be noted that in addition to the information collected through the survey, a unanimous comment from the professors involved in this study was that at the beginning development of the immersive resources, time and resources were required, for example in the evaluation and purchase of recording and viewing equipment or in the shooting and editing videos. Likewise, this initial effort allows the creation of future versions of the immersive resources with little extra effort.

5. Conclusions

In the case of Chemical Engineering, the limited resources available and the specificity required made necessary the creation and development of own immersive VR-based resources. Specifically, a 360° virtual tour video (360VTV) was created and used as an element of promotion and dissemination of the Chemical Engineering Degree among high school students. The viewing of this VR resource with the HMDs allowed the virtual visit to the pilot plant and laboratories at the Faculty of Sciences during the routine practical lessons. This activity was rated very positively by the high school students through a post-survey, highlighting the average score obtained in the rating overall of this VR resource (4.4 out of 5) and the increased interest in the Chemical Engineering Degree after the activity. In addition, aspects to improve were identified, mainly elements that would expand the information shown to the viewer in different remarkable places of the visit, through a narrator voice or emergent action points (hotspot).

In addition, an immersive experiential learning tool (ELT) was developed with the ActivePresenter software, which was adapted and integrated into the Separation Operations MOOC. In it, undergraduate students, in advance of the face-to-face practical sessions, had access to the 360° virtual video of each practical activity, additional information, explanatory videos of the professor and a simulation step by step of the procedure. The results of the post-survey suggest that the students found it to be a very useful learning tool.

From the perspective of the professors, the resources immersive generated were highly valued as a tool for disseminating and supporting teaching. The development of the virtual reality resources specific required time and effort, mainly in the filming and editing of the 360° videos, as well as in the development of the interface for ELT. This initial work allows us to create tailored versions of the immersive resources with little extra effort.

Additionally, as future lines of work, other possibilities to interact with content shown were detected, such as 3D models that can be manipulated with hand gestures or controllers, or even the development of mini-labs based on VR, which could include tests in order to determine the level of competence achieved by Chemical Engineering students.

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Appendix A

Figure A1. Screenshots as an example of four components Distillation ELT (Spanish). (**a**) Theoretical explanation; (**b**) Video of the practice; (**c**) Simulation; (**d**) 360° practice.

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