

Improvements in skill-based learning in Chemical Engineering laboratory practicals through the use of flipped classroom methodology assisted by video tutorial.

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Mejoras en el aprendizaje basado en habilidades en prácticas de laboratorio de Ingeniería Química mediante el uso de la metodología de aula invertida asistida por video tutorial.

Millores en l'aprenentatge basat en habilitats en pràctiques de laboratori d'Enginyeria Química mitjançant l'ús de la metodologia d'aula invertida assistida per video tutorial.

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ABSTRACT

Laboratory practicals in the Industrial Chemical Engineering Bachelor's Degree are a scenario where students can test their hypotheses, and which facilitate the understanding of theoretical concepts, calculation methodologies and the influence of operating conditions. They foster a learning environment based on the essential competencies of 'learning to know', 'learning to do', 'learning to live together' and 'learning to be'. However, these subjects require individualized attention so that our students can fully understand what, how and why they should do. When the groups of students are large, the teacher cannot provide quick advice to everyone and the student may face technical difficulties due to their lack of previous experience in laboratory environments. This fact usually leads to student's insecurity and poor learning of lab-work skills. This study shows evidence of improvements in learning when implementing the flipped classroom teaching methodology based on the use of video tutorials in experimental subjects. The video tutorials, carefully designed to cover both fundamental concepts and experimental procedures in laboratory practicals, generate a more autonomous learning environment and a more active role of the student in his/her own learning process compared to traditional methods. In fact, 100% of the students rated the overall use of the video tutorials in

these laboratory practicals with a score of 4-5 out of 5. It is noticeable that the use of the video tutorials made the students feel more confident in facing their assignments. Furthermore, 92% considered that this teaching innovation should be extended to all the experimental subjects that make up their study programme.

Keynote words: Chemical Engineering, flipped classroom, video tutorial, laboratory practicals, skill-based learning

RESUMEN

Las prácticas de laboratorio del Grado en Ingeniería Química Industrial son un escenario donde los estudiantes pueden contrastar sus hipótesis, y que facilitan la comprensión de conceptos teóricos, metodologías de cálculo y la influencia de las condiciones de operación. Fomentan un entorno de aprendizaje basado en las competencias esenciales de "aprender a conocer", "aprender a hacer", "aprender a vivir juntos" y "aprender a ser". Sin embargo, estas materias requieren de una atención individualizada para que nuestros estudiantes puedan entender plenamente qué, cómo y por qué deben hacer. Cuando los grupos de estudiantes son grandes, el profesor no puede brindar consejos rápidos a todos y el estudiante puede enfrentar dificultades técnicas



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debido a su falta de experiencia previa en ambientes de laboratorio. Este hecho suele conducir a la inseguridad de los estudiantes y a un pobre aprendizaje de las habilidades para el trabajo de laboratorio. Este estudio muestra evidencia de mejoras en el aprendizaje al implementar la metodología de enseñanza de aula invertida basada en el uso de videotutoriales en materias experimentales. Los videotutoriales, cuidadosamente diseñados para cubrir tanto conceptos fundamentales como procedimientos experimentales en las prácticas de laboratorio, generan un ambiente de aprendizaje más autónomo y un papel más activo del estudiante en su propio proceso de aprendizaje en comparación con los métodos tradicionales. De hecho, el 100% de los estudiantes valoró el uso general de los videotutoriales en estas prácticas de laboratorio con una puntuación de 4-5 sobre 5. Llama la atención que el uso de los videotutoriales hizo que los estudiantes se sintieran más seguros a la hora de afrontar sus asignaciones. Además, el 92% consideró que esta innovación docente debería extenderse a todas las materias experimentales que componen su plan de estudios.

Palabra clave: Ingeniería Química, aula invertida, vídeo tutorial, prácticas de laboratorio, aprendizaje basado en habilidades

RESUM

Les pràctiques de laboratori del Grau d'Enginyeria Química Industrial són un escenari on els estudiants poden provar les seves hipòtesis, i que faciliten la comprensió dels conceptes teòrics, les metodologies de càlcul i la influència de les condicions de funcionament. Fomenten un entorn d'aprenentatge basat en les competències essencials d'"aprendre a saber", "aprendre a fer", "aprendre a conviure" i "aprendre a ser". Tanmateix, aquestes matèries requereixen una atenció individualitzada perquè els nostres alumnes entenguin perfectament què, com i per què han de fer. Quan els grups d'alumnes són nombrosos, el professor no pot donar un assessorament ràpid a tothom i l'estudiant pot trobar dificultats tècniques per la seva manca d'experiència prèvia en entorns de laboratori. Aquest fet sol conduir a la inseguretat dels estudiants i a un mal aprenentatge de les habilitats de treball de laboratori. Aquest estudi mostra evidències de millores en l'aprenentatge a l'hora d'implementar la metodologia d'ensenyament flipped classroom basada en l'ús de videotutorials en assignatures experimentals. Els videotutorials, curosament dissenyats per cobrir tant conceptes fonamentals com procediments experimentals en pràctiques de laboratori, generen un entorn d'aprenentatge més autònom i un paper més actiu de l'estudiant en el seu propi procés d'aprenentatge en comparació amb els mètodes tradicionals. De fet, el 100% dels estudiants van valorar l'ús global de les videotutorials en aquestes pràctiques de laboratori amb una puntuació de 4-5 sobre 5. Es nota que l'ús de les videotutorials va fer que els estudiants se sentissin més segurs per afrontar el seu encàrrec. A més, el 92% considera que aquesta innovació docent

s'hauria d'estendre a totes les matèries experimentals que integren el seu pla d'estudis.

Paraules clau: Enginyeria Química, aula invertida, vídeo tutorial, pràctiques de laboratori, aprenentatge basat en habilitats

INTRODUCTION

Current generations of students feel more comfortable with information and communication technologies (ICTs) resources, as they create learning environments that are more attractive and friendly to them¹⁻². Furthermore, the globalization of Higher Education has introduced new scenarios that involve less face-to-face teaching and greater integration of digital culture in teaching-learning processes, especially since the irruption of the COVID-19 pandemic when face-to-face teaching was not possible. Nevertheless, the evolution of ICTs is being so rapid that it is demanding continuous updating of teachers, but at the same time it is preventing an adequate analysis of its impact and educational possibilities³. This results in the uncertainty of many teachers about how to use ICT tools in the classroom, sometimes they even feel uncomfortable using them.

In the context in which this teaching innovation is developed, the experimental subjects of the Industrial Chemical Engineering Bachelor's Degree offer a practical approach that demonstrates and explains the foundations of Chemical Engineering. The teaching-learning process focuses on the handling of laboratory instruments and/or equipment, as well as the successful collection of experimental data to obtain the best results. In addition, the work carried out in the laboratory practicals successfully links the cognitive skills ("learning to know") acquired in the previous theoretical subjects with the instrumental skills ("learning to do") implemented in the laboratory practicals, as well as the development of other more transversal skills ("learning to be" and "learning to live together") that will be demanded by students in their professional careers⁴. In consequence, this work environment allows students to contrast the proposed hypotheses and helps them understand the theoretical concepts involved, the calculation methods and the influence of the process variables⁵.

But the successful development of these subjects entails certain difficulties. As Canino et al.⁶ previously pointed out, the main concern is that the students who access them do not usually have previous experience in laboratory practical work or they have not previously taken the recommended theoretical subjects. Consequently, these students usually demand continuous supervision throughout the practicals, with repeated explanations of the experimental work. This hampers the suitable monitoring of good laboratory for each student to effectively evaluate their acquisition of skills during the experimental work session. In addition, the large number of students, added to the different types of practical assignments that are carried out

simultaneously, makes it difficult for the teacher to provide each student with key guidelines on each one and the management of laboratory instrumentation. In this sense, the authors' own experience is that having to wait for the teacher's explanations usually delays the student's data collection process, which shortens the time available to carry out the practicals. This fact causes some impatience in the students about starting the practical work without paying the right attention to the theoretical concepts involved or without having a global understanding of it, limiting their learning. Thus, as previously stated by Hoe and Wai⁷, achieving teaching-learning objectives in these circumstances is a task that requires a lot of work and time, and the results are sometimes not successful.

These circumstances underline the need to reorient teaching-learning methods in experimental subjects towards approaches that reduce direct dependence on the teacher, but without harming the development of the student's competencies and the achievement of the expected learning results. On the one hand, the flipped classroom methodology encourages students to carry out lower cognitive level learning before attending classes and to become a precursor to their own learning process⁹. In addition, it allows deeper and more active learning in face-to-face sessions, enhancing the interaction between teacher-student and student-student¹⁰⁻¹². On the other hand, video tutorials have proven to be a very effective interactive teaching tool for laboratory practicals¹³⁻¹⁵. In fact, as Bravo et al.¹³ have shown, the familiarity of multimedia content with new generations makes these video tutorials an excellent facilitator of learning, as well as motivating. They provide students with the basic concepts on which the laboratory practicals are based, as well as clear visual instructions on what to do and how to do it that, otherwise (written instructions), would be unfeasible. Furthermore, the use of the video tutorial allows total adaptation to the different learning rhythms of the students and unlimited access to visualizations before, during or after the face-to-face session¹⁶⁻¹⁷.

In this work, a previous study published by Pablo-Lerchundi et al.¹⁴ has also been taken into account. Curiously, it revealed a clear preference on the part of the students for the teacher's face-to-face explanations over watching the video tutorial. Pablo-Lerchundi et al. interpreted it as evidence of lack of maturity for autonomous learning and overdependence on the teacher as a source of learning. We have considered that factors such as a poor design of the video tutorial¹⁸ or the unnecessary total absence of teacher supervision may have influenced these results. In any case, these aspects have been carefully taken into account in this work. Thus, with the aim of solving the problems detected and improving the teaching-learning process in the experimental subjects of the Industrial Chemical Engineering Bachelor's Degree, the teaching team which has participated in this work, has implemented and evaluated a flipped classroom methodology assisted by video tutorials. This can facilitate the highly valued learning by competencies.

METHODOLOGY

Participants

The teaching methodology was implemented during the second semester of the 2021-22 and 2022-23 academic years in three selected subjects of the Industrial Chemical Engineering Bachelor's Degree taught at the Higher Technical School of Engineering (ETSI) of the University of Huelva (Spain). The subjects were "Experimentation in Chemistry" (EC), "Experimentation in Chemical Engineering I" (ECE I) and "Unit Operations of Chemical Engineering II" (UOCE II), all of them compulsory, with a teaching load of 6 ECTS. EC belongs to the 1st course, whilst both ECE I and UOCE II belong to the 3rd course. The number of participating students was 15, 11 and 9 (2021-22) and 18, 15 and 9 (2022-23), regarding the three aforementioned subjects.

Supporting materials provided to students in the laboratory practicals

- *Instructions, key guidelines and supplementary information*

Before the face-to-face sessions, students are provided with the basic theoretical fundamentals and guidelines for the development of the practicals through instruction documents and supplementary information available online on the virtual platform Moodle. These materials provide the student with a brief summary with the theoretical fundamentals, the objectives, the reagents and materials to be used, the experimental procedure, as well as examples of graphs and calculations to be carried out, the reference bibliography and, where appropriate, a final section of potential conflict issues.

- *Video tutorials*

The video tutorials have been created taking into account the recommendations given by Brame¹⁸ in order to create a multimedia document that guides the students so that, clear and autonomously, they can understand: the theoretical concepts, the experimental steps to be carried out, the handling of laboratory equipment, and how to obtain the data that will lead to obtaining the desired results. The students were allowed to view the video tutorial as many times as needed before, during or after completing their practicals. The video tutorials were prepared by each teacher following an organizational structure to give them uniformity. All of them are available on the YouTube channel "Ing. Quimica_UHU". The recording and subsequent editing of the video (including music and text) was done using the Filmora Wondershare Video Editor software.

Methodological approach to laboratory practicals

In each laboratory session, students were divided into groups of two or three members. In the 2021-22 academic year, when the implementation of this teaching innovation began, for each subject, the teacher selected two specific laboratory practicals with a similar degree of difficulty: practical assignment A "with video tutorial" (+VT) and practical assignment B "without video tutorial" (-VT). For each one, three sessions were established:

- In the first session, following the work dynamics based on the flipped classroom methodology, one day before to the face-to-face session in the laboratory, all students had access the instruction documents and supplementary information through the virtual platform Moodle and were recommended to read them carefully.
- For EC the instructions were prepared to help students to handle the experimental methodology of the practicals. For “Unit Operations of Chemical Engineering II,” instructions with the key guidelines were prepared to help students become familiar with Aspen Plus simulations of both fractional distillation and absorption. However, for ECE I the instructions only provided guidance on the practice to be performed and the objective to be achieved. Therefore, students had to analyse the instruction documents and supplementary information received from the practical and prepare a practical script. This script consisted of an introduction to the basic concepts and theoretical equations of the practical and describing the experimental procedures that they should do in the laboratory to achieve the objective of the assigned practical. In any case, just before starting the second session, the corresponding video tutorial was made available to the groups that were going to carry out practical assignment A (+VT).
- In the second session, all students accessed the laboratory to carry out the practices. Regardless of whether the group carried out practical assignment A (+VT) or practical assignment B (-VT), they had printed instructions on the experimental procedure and on-site explanations on the correct use of instruments or laboratory equipment by the teaching staff who, in addition, answered any questions that might arise during the development of the practicals. The only difference is that students doing practical assignment A (+VT) could watch the video tutorial during this session as many times as needed.
- In the third session, each group had to prepare a final report of each practical assignment. Students were encouraged to be creative and traditional written reports were replaced with a report in multimedia format (mp4 is the preferred format). This format consisted of a 10-15 min. video where the theoretical basis, the objectives, the experimental methodology, the discussion of the results obtained and the conclusions were transmitted clearly and with scientific rigor. To edit these video reports, a wide variety of virtual environments were available, such as Filmforth, Filmora, Power Point, Adobe Captivate, Camstudio and even Zoom.

In contrast, in the 2022-23 academic year, all students carried out their laboratory practicals with the help of the flipped classroom methodology enhanced by the use of video tutorials.

Table 1. *Students’ survey on the flipped classroom teaching methodology based on the use of video tutorials.*

| Questions | |
|---|-----------------|
| I liked the video tutorials. | Q ₁ |
| The video tutorial has sparked my curiosity and captured my attention. | Q ₂ |
| The explanations and instructions were understandable and easy to follow. | Q ₃ |
| Watching the video tutorial, I experienced boredom | Q ₄ |
| The music in the video tutorial distracted me. | Q ₅ |
| How many times have you watched the video tutorial before carrying out the practical assignment? Indicates the number (5 being the maximum number available). | Q ₆ |
| I have watched the video tutorial during the practice to resolve doubts. | Q ₇ |
| The video tutorial has been very useful for me to understand the objective of the practical assignment. | Q ₈ |
| The video tutorial has been very useful for me to know the experimental procedure to carry out the practical assignment. | Q ₉ |
| The video tutorial has been very useful for me to know the expected learning outcomes of the practical assignment. | Q ₁₀ |
| By watching the video tutorial, I felt very confident to carry out the practical assignment autonomously. | Q ₁₁ |
| I have needed the teacher’s help carry out the practical assignment. | Q ₁₂ |
| I consider it useful to have video tutorials in all the practical subjects of my study programme. | Q ₁₃ |
| Overall assessment of the use of video tutorial. | Q ₁₄ |

Evaluation

Any innovative teaching methodology must incorporate a process of evaluating its effectiveness, in order to assess knowledge acquisition and decide whether or not to maintain it. For a more precise and complete evaluation of the flipped classroom methodology assisted by video tutorials, an assessment methodology based on that described by Kong¹⁹ has been followed. Pre- and post- tests were designed for each subject. These were approved by all the teaching staff participating in this experience. Both questionnaires were administrated online, through Google Forms. The pre-test, which consisted of 10 questions with 4 answers where only one was correct, was carried out after the first session and before visualizing the video tutorial, to evaluate prior knowledge of the practice. Comparison of results of both pre- and post- tests taking into account the students did practical (+VT) and (-VT) allowed us to discern the degree of learning achieved by each student thanks to the previous work with the instructions, guidelines and complementary materials provided. During the second session, each teacher had the opportunity to observe whether the students who had watched the video tutorials improved their prior understanding of the practical assignment to be carried out. It was also evaluated whether the students had successfully developed procedural and instrumental skills, as well as the quality of the lab practices and the experimental

results obtained. Once the second session had finished, all students took a post-test with 10 theoretical-practical questions. This questionnaire made it possible to assess the achievement of the planned learning objectives. In both questionnaires, scores were assigned on a scale of 0 to 10 points. In this way, it was possible to compare the scores obtained by those who worked under the flipped classroom methodology with video tutorial and those for whom this support was not available.

At the end of the subject, feedback was obtained from the students about this flipped classroom teaching methodology based on the use of video tutorials through an online survey (Table 1), using a Likert-type scale from 1 (strongly disagree) to 5 (strongly agree). As commented by Lukas et al.²⁰, the simplest and quickest method that is usually used to evaluate different aspects related to teaching is the use of questionnaires, which must be well designed according to standard quality criteria²¹. The students' survey was carefully designed and agreed by the five teachers participating in this study to ensure validity. It is noteworthy that, in some cases, the teachers have more than 15 years of experience in their subjects. Moreover, reliability was assessed through the well-known α of Cronbach test²¹.

RESULTS AND DISCUSSION

In this work, a group of lecturers have designed and edited a series of video tutorials about specific laboratory practicals developed within the Industrial Chemical Engineering Bachelor's Degree. This was intended to help students improve their learning and know-how, i.e. the experimental and conceptual approach in the Chemical Engineering laboratory practicals. This teaching strategy provides students with clear, step-by-step demonstrations of complex procedures, helping them visualize and better understand the processes before performing them in the laboratory. With this purpose, the video tutorials were accessible anytime, based in a flipped classroom methodology strategy, allowing students to revisit content as needed, reinforcing their learning at their own pace. This is comparable to a situation when a person needs to do something he/she has never done before and he/she opts for visualizing instructions in YouTube. With this video tutorials, we offer them a consistent and standardized way of presenting instructions, to ensure that all students receive the same guidance, which enhances preparation and improves the quality of their lab work.

In this sense, all the teachers involved in this study agreed that the students who watched the video tutorial acquired greater autonomy, since they did not need as much attention from the teacher during the development of the practicals. This allowed them to better understand the learning objectives of the practicals, complete the experimental part faster and be able to repeat the data collection a greater number of times, substantially improving the results obtained. Furthermore, these students tended to be more autonomous, confident, and competent compared to previous courses. Moreover, the experimental results were better.

As previously mentioned, to analyse whether this flipped classroom methodology assisted by video tutorials had any effect on improving their understanding of the contents, all students filled out an online questionnaire with 10 multiple choice questions on theoretical and practical concepts of the assigned topic, before and after carrying out the laboratory practicals. The questionnaires were scored between 0 and 10 points.

Figure 1 shows a comparative evaluation of the student's grades before and after carrying out the laboratory practicals assisted by video tutorials and not, for all the subjects involved in the 2021-22 academic year. The diagonal ($y = x$) was drawn as a reference. In EC, it can be seen that 9 out of 12 students improved their scores after completing practical assignment A (+VT) assisted by tutorial video, compared to practical assignment B (-VT), in which only 6 out of 9 students improved their scores. One of the remaining 3 students had lower scores. In ECE I, it can be seen that 3 out of 5 students improved their score. Even so, one student reduced his/her grade by one point. Surprisingly, in this subject no one improved his/her scores in practical assignment B. In UOCE II, 8 out of 10 students improved their grades, compared to 7 out of 9 students in practical assignment B. In this case, no one reduced their scores after the practical session. In general, it should be noted that video tutorials yielded higher grades.

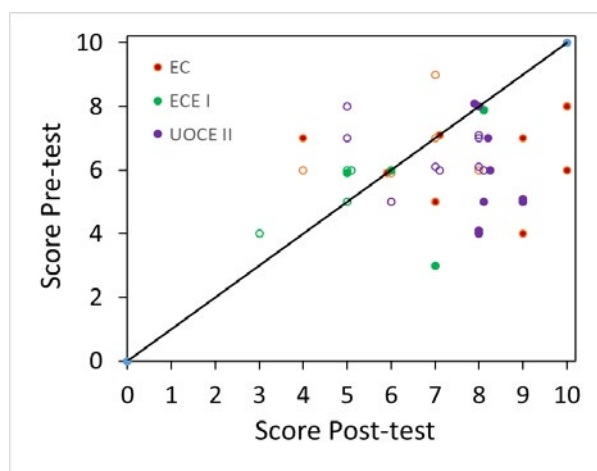


Figure 1. Comparative evaluation of the scores obtained in the pre-test and post-test carried out in practical assignment A (+VT) (filled symbols) and practical assignment B (-VT) (empty symbols) in the 2021-22 academic year.

Table 2 establishes a comparative analysis between the ratings obtained by students in the pre-test and post-test during the 2021-22 academic year, both with and without watching the video tutorial. For those who used the video tutorial in the EC, ECE I and UOCE II subjects, a performance improvement of 31.7%, 11.4% and 41.4% respectively, was observed. However, for students who carried out practical assignment B, i.e., without the use of the video tutorial, their percentage of improvement was considerably lower, being 17.0%, 0.0% and 7.8% respectively.

Table 2. Grades obtained by students before (pre-test) and after (post-test) carrying out their practical assignment in the 2021-22 academic year

| PRACTICAL ASSIGNMENT | EC | | ECE I | | UOCE II | |
|----------------------|-----------|-----------|-------------|-------------|------------|------------|
| | Pre-test | Post-test | Pre-test | Post-test | Pre-test | Post-test |
| A (+VT) | 6.3 ± 1.5 | 8.3 ± 1.9 | 6.14 ± 2.01 | 6.84 ± 1.35 | 5.8 ± 1.56 | 8.2 ± 0.44 |
| B (-VT) | 5.9 ± 1.5 | 6.9 ± 1.5 | 5.25 ± 0.96 | 4.53 ± 1.02 | 6.4 ± 0.88 | 6.9 ± 1.27 |

In the case of EC, the benefits of the flipped classroom methodology were noticeable. As commented before, the laboratory practicals carried out in EC were based on the theoretical-practical fundamentals of Chemistry, which are partially addressed in Secondary School, and further introduced and developed in the subjects “Chemistry I” and “Chemistry II” in Higher Education. Therefore, the flipped classroom teaching methodology based on the use of video tutorials helped those students better understand the objectives, the theoretical and fundamental concepts and the experimental protocols of these elementary practicals, in contrast to other students that were only provided with the traditional supporting material.

On the other hand, given that in ECE I the theoretical and fundamental concepts are taught in two previous subjects, each academic year we have some students who either have not passed those subjects, or have not even taken them. This circumstance makes the

teaching-learning process more difficult as they lack the prior knowledge necessary to carry out the practicals successfully. This is demotivating, and might be the reason why no one improved his/her scores in practical assignment B (-VT) of this subject. Therefore, significant differences were found in the participants’ scores between practical assignments A (+VT) and B (-VT) of ECE I, even when they had never studied the theoretical framework of the unit operations involved. It can be concluded that the use of video tutorials helped students clarify the basic concepts and reinforce their understanding of the practicals, and even motivated them to assume a much more active role^{14,16,22}. This fact clearly demonstrates that flipped classroom based on video tutorials yielded the improvement of the teaching-learning process in this experimental subject. In addition, it is worth pointing out that in the final exam of the subject, we have detected that the students who used the video tutorials during their practical assignments performed better in the related questions.

Table 3. Results (in percentage, %) of the students’ survey on the flipped-classroom methodology based on video tutorials in the 2021-22 and 2022-23 academic years. The reliability index, α of Cronbach, of each questionnaire is included.

| Questions | EC | | | | ECE I | | | | UOCE II | | | |
|------------------------------------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|---------|------|
| | 2021-22 | | 2022-23 | | 2021-22 | | 2022-23 | | 2021-22 | | 2022-23 | |
| | 1-2 | 4-5 | 1-2 | 4-5 | 1-2 | 4-5 | 1-2 | 4-5 | 1-2 | 4-5 | 1-2 | 4-5 |
| Q ₁ | 0.0 | 93.3 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 93.3 | 0.0 | 100.0 | 0.0 | 88.9 |
| Q ₂ | 6.7 | 86.7 | 0.0 | 100.0 | 0.0 | 81.8 | 0.0 | 93.3 | 0.0 | 100.0 | 0.0 | 88.9 |
| Q ₃ | 0.0 | 93.3 | 0.0 | 94.4 | 0.0 | 100.0 | 0.0 | 93.3 | 0.0 | 77.8 | 0.0 | 88.9 |
| Q ₄ | 40.0 | 46.7 | 50.0 | 44.4 | 90.9 | 9.1 | 73.3 | 20.0 | 77.8 | 0.0 | 33.3 | 33.3 |
| Q ₅ | 66.7 | 13.3 | 61.1 | 16.7 | 90.9 | 9.1 | 86.7 | 6.7 | 55.6 | 0.0 | 44.4 | 44.4 |
| Q ₆ | 42.9 | 14.3 | 72.2 | 5.6 | 90.9 | 0.0 | 66.7 | 6.7 | 77.8 | 11.1 | 100.0 | 0.0 |
| Q ₇ | 42.9 | 35.7 | 22.2 | 50.0 | 63.6 | 18.2 | 40.0 | 60.0 | 0.0 | 88.9 | 44.4 | 33.3 |
| Q ₈ | 0.0 | 93.3 | 0.0 | 94.4 | 0.0 | 90.9 | 0.0 | 100.0 | 11.1 | 77.8 | 0.0 | 55.6 |
| Q ₉ | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 86.7 | 0.0 | 100.0 | 0.0 | 66.7 |
| Q ₁₀ | 0.0 | 93.3 | 0.0 | 100.0 | 0.0 | 63.6 | 0.0 | 66.7 | 11.1 | 77.8 | 0.0 | 55.6 |
| Q ₁₁ | 0.0 | 93.3 | 0.0 | 94.4 | 0.0 | 81.8 | 0.0 | 80.0 | 0.0 | 100.0 | 0.0 | 66.7 |
| Q ₁₂ | 46.7 | 20.0 | 22.2 | 27.8 | 54.5 | 27.3 | 26.7 | 20.0 | 33.3 | 0.0 | 44.4 | 22.2 |
| Q ₁₃ | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 90.9 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 55.6 |
| Q ₁₄ | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 93.3 | 0.0 | 100.0 | 0.0 | 77.8 |
| α of Cronbach ²³ | 0.491 | | 0.634 | | 0.725 | | 0.716 | | 0.486 | | 0.647 | |

Regarding the UOCE II subject, the flipped classroom methodology seems to have had only a moderate effect. It can be said that the students, through their own work at home, were able to understand the fundamentals of the respective unit operations, which at least guaranteed an adequate understanding of the practical work. Specifically, the pre-test yielded an average class score of 6.4 and 5.8 out of 10 points, in Distillation (practical assignment B) and Absorption (practical assignment A), respectively. Higher scores in the post-test were obtained in both cases, suggesting that the simulations helped clarify concepts and reinforce understanding in both Distillation and Absorption. However, it is worth mentioning that the video tutorial helped those students who had obtained the lowest scores in Distillation to perform at the same level as their peers in Absorption, resulting in a large increase in the average score of the class.

Finally, students were invited to respond and provide feedback on the teaching approach and comment on the flipped-classroom methodology based on video tutorials. The results are compiled in Table 3. Although the actual responses were on a scale of 1 (strongly disagree) to 5 (strongly agree), for the sake of clarity, we have decided to show the results grouped as 1-2 (in disagreement) and 4-5 (strongly agree) per academic year.

As can be appreciated in Table 3, with the exception of 2021-22 for EC and UOCE II, all tests showed a suitable reliability index. Only in the case of ECE I, the α of Cronbach gives values above 0.71, thereby with high level of reliability. In addition, student's satisfaction in the EC and ECE I remains the same in the two academic years analysed. However, a significant decrease of the student satisfaction was observed in the 2022-23 academic year for UOCE II. In general, the results obtained for the first three questions regarding personal acceptance of the video tutorial (in relation to whether they liked it (Q_1), its potential of arousing their curiosity and capturing their interest (Q_2) and understandability of the explanations and instructions (Q_3)), were rated in the interval of 77.8-100% in all cases. A high number of students, 93.9 and 90.9% (2021-22) and 94.4 and 100% (2022-23), related to EC and ECE I, respectively, stated that the video tutorials helped them successfully understand the objective (Q_8) and the experimental procedure (Q_9) of the practical assignment, despite the fact that some admitted to have used them rarely during their implementation. However, only in EC, such high number of student declared that the video tutorial has been very useful for them to know the proposed learning results in practice (Q_{10}). Furthermore, it is worth noting that most of students valued the use of the video tutorial in these subjects very positively (Q_{14}). All the students who have used video tutorials have expressed the suitability of having video tutorials in all other experimental subjects of the Industrial Chemical Engineering Bachelor's Degree curriculum (Q_{13}).

It must also be emphasized that the results obtained have been excellent as they indicate an increase in the student's autonomy (Q_{11}). In the 2021-22 academic year,

more than 93.3% (in EC), 81.8% (in ECE I) and 100% (in UOCE II) of the students have gained confidence when carrying out the practices, opting for resorting to the video tutorial rather than requesting the teacher's assistance. Thus, related with question Q_{12} , none of the 9 students in UOCE II and only 3 students in the remaining subjects needed personal assistance to carry out the practicals in the 2021-22 academic year. In the following course, 2022-23, the number of students who declared to feel confident enough so as to work autonomously was reduced to 66.7%. It's worth to mentioning that although the students felt confident enough to carry out the practice independently (Q_{11}), they still needed the teacher's help (Q_{12}). Despite that, these very positive results reaffirm that the implemented methodology provides a valuable didactic approach and encourage to continue in future academic years and in new subjects.

Moreover, students reported some interesting comments, the most outstanding of which are detailed below:

- In my opinion, the video tutorial was useful. I think it is a good tool when it comes to improving previous understanding of the practicals. It would have been a good decision to follow such strategy in all practical assignments, because this way you get a general idea before doing them.
- I find the video tutorial very useful, because when I watched it before doing the practicals I planned the different steps I had to follow in the laboratory.
- I think that the use of video tutorial makes it easier to follow the steps, not only in the laboratory practicals, but also in the use of different software.
- I think that a video can complement the written instructions of the practicals.

In relation to the opinion of the participating teachers (Table 4), the main drawback was that the preparation of the materials took a lot of time and involved a lot of work. Most of them had no prior experience creating and editing videos. However, all teachers were very satisfied with the results, since the students learned and performed much better than in previous years (see Table 4). Additionally, once prepared, the materials can be reused in future years. It is important to note that some lecturers scheduled a seminar on the use of video editing software, such as Filmora, so that students could prepare their own audio-visual reports. Making audio-visual materials is a transversal competence which students will have the opportunity to put into practice in other subjects during their Industrial Chemical Engineering studies. Such typology of materials may indeed be very valuable for their future professional career too, given the massive current use of multimedia contents to promote products, projects, ideas, etc. In our opinion, the experience was very enriching and we would definitely recommend it to other teachers. For this reason, we will continue to prepare new materials every year so that after four or five years all the practical contents will be available in the form of video tutorials.

Table 4. *Teacher's survey on the flipped-classroom methodology based on video tutorials.*

| Questions | RATING | |
|---|--------|--------|
| | 1-2 | 4-5 |
| I have made video tutorials in other subjects or courses. | 57.1% | 14.3% |
| I have previous experience in video editing and making video tutorials. | 28.6% | 28.6% |
| The training material and seminar provided by the coordinator allowed me to develop the experience. | 0.0% | 100.0% |
| The use of video tutorials is appropriate for the topic in which it was carried out. | 0.0% | 100.0% |
| The video tutorial facilitated the use of the lab equipment needed to carry out the practicals. | 0.0% | 100.0% |
| I believe that the use of video tutorials has improved students' performance in laboratory practicals. | 0.0% | 100.0% |
| The time invested in completing the video tutorial is not compensated by the improvement in learning outcomes. | 85.7% | 14.3% |
| I noticed that the students who used the video tutorials were more motivated and self-confident when doing the practical assignments. | 0.0% | 100.0% |
| The resources used (laboratory equipment, computer, video editing software, etc.) seemed adequate. | 0.0% | 100.0% |
| I would like the use of video tutorials to be extended to the rest of the subjects in the curriculum. | 0.0% | 100.0% |
| I consider it useful to have video tutorials in all the practical subjects of the study programme. | 0.0% | 100.0% |
| Overall assessment of the use of video tutorials. | 0.0% | 100.0% |

CONCLUSIONS

When students are faced with practical subjects, they often encounter difficulties in understanding what they are doing in the laboratory, how they are doing it and why they are doing it. Personalized and immediate attention from the teacher is demanded so that the students can outline the experiments and handle the instruments with confidence. However, in large groups, this attention is limited, which can lead to a lack of student independence, fear of making mistakes, and additional pressure due to limited time to perform the assigned practical work.

With the introduction of a flipped classroom methodology based on video tutorials in these practical subjects, our students have gained both independence and confidence in laboratory work. Now they are more aware of what they have to do and how to do it. Bidirectional communication between student and teacher improved, yielding faster work and more efficient handling of the materials. As a result, we have created a more active and, at the same time, more collaborative self-learning environment among students, which facilitates the understanding of theoretical and procedural aspects and promotes the acquisition of the skills and competencies required in practical subjects.

In fact, all teachers have noticed a significant improvement in the results obtained in the post-tests among students who watched the video tutorials compared

to those who did not. Furthermore, all students have valued this methodology very positively, demonstrating great satisfaction about the advantages of video-based learning. These indicators allow us to foresee future implementations of the use of video tutorials in other subjects.

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