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Design and assessment of a project-based learning in a laboratory for integrating knowledge and improving engineering design skills

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A R T I C L E I N F O

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A B S T R A C T

Mechanical Design is a subject usually included in Chemical Engineering Degrees. In this work, we present the application of a project-based learning to the lab in two different engineering degrees, in of one the most time-consuming and difficult subjects of their programs. These two degrees, Mechanical and Chemical engineering degrees, were selected in order to compare the learning outcomes and satisfaction with the activity in the degree more related to mechanical concepts and the Chemical engineering degree. Moreover, to enhance students' enthusiasm and motivation, these sessions included an innovative manufacturing technology, 3D printing, and digital image correlation (DIC). Before each practical session, the students are encouraged to watch an online video with the fundamental aspects. In order to assess the success of this methodology, after finishing the lab sessions, the students answered a non-formal quantitative survey. The results showed that the proposed project-based learning had the ability to help integrating the knowledge and improve the skills included in the main competences. Although these results are encouraging, there are still parts of the lab activity that should be improve in order to make the activity less time consuming and the most difficult part being easier for the students.

1. Introduction

The curricula of practically all Chemical Engineering degrees follow the guidelines necessary for obtaining the professional degree in the field of engineering, which includes technical knowledge of chemistry, biochemistry, engineering, mechanical and materials science. Therefore, *Mechanical Design* subject is usually included in most Chemical Engineering Bachelor degrees around the world. The knowledge acquired by the students in this discipline is important for Chemical engineering design in real problems of their future profession. These real problems can be mechanical design of piping systems or of process equipment as thin-walled vessels under pressure or combined loads (Towler and Sinnott, 2012). In this context, graduates must be able to design specified machines, equipment and processes.

Mechanical design is a core discipline within most engineering degrees concerning industrial fields. However, not all the degrees has the same ECTS credits (Bologna ECTS credit scheme) to develop the basis and fundamentals of this subject. *Mechanical design*, the subject in Chemical and Energy engineering degrees, includes concepts of three different disciplines: *Mechanics*, *Elasticity and Strength of Materials and Theory of Machines and Mechanisms.* All these disciplines are included as they are necessary to accomplish the requirements to obtain the professional qualifications of the degree. Therefore, the understanding of the basis and fundamentals of *Mechanical design* is very difficult for the students due to the perception of distance to the rest of their degree curriculum and the lack of applications to their future professional activity. Consequently, students perceive these courses negatively which leads to demotivation and high level of failure. In order to change this perception, it is necessary to introduce new teaching methodologies emphasizing the engagement of the students in the learning process to achieve a better knowledge acquisition (Fraile García et al., 2017).

The traditional learning of both *Mechanical Design* and *Elasticity and Strength of Materials* are still carried out. This approach is usually deductively. A well-established precept in education is that students are most strongly motivated to learn things they clearly perceive a need to know (Prince and Felder, 2006). A preferable alternative is inductive teaching and learning. Instead of beginning with theories and principles and then getting to applications, the teacher starts with a case study to analyze, a project to design or a complex-real-world problem to solve.

Inductive teaching methods compasses a range of instructional

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methods that includes inquiry learning, problem-based learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching. All these methods have many features in common. All of them are student-centered and, almost always, involve active learning by making students discuss questions and solve problems in class. In much of the work, these methods also make students work in groups out of class, promoting the collaborative active learning. There are also differences among the inductive teaching methods aforementioned. Prince and Felder (2006) show a table that summarized the defining characteristics of all these methods, where it is stated their main similarities and differences.

University teaching techniques are changing as educators seek to achieve both quality learning and more effective teaching (Biggs et al., 2011). In reaction to the classical teacher-centered approach, new methods aim to enhance knowledge acquisition by more active participation of students in their learning, thus achieving greater motivation (Chi and Wylie, 2014; Ballesteros et al., 2021). Various methods have been proposed to increase students' motivation and participation. There are many different teaching methodologies. In *flipped learning* part of the syllabus is worked on at home before the corresponding class. This approach is used as means of applying the knowledge gained (Greenwood and Mosca, 2017). Another example is *gamification,* where the principles of the game are oriented towards processes or objectives, which may be non-playable in themselves, to make them more attractive (De la Flor et al., 2020). Finally, project and problem-based learning that works with a problem presented to the students who must investigate and offer adequate solutions (Sayyah et al., 2017).

Among these learning methodologies, problem-based learning has been used for educational ends in different fields since they are familiar to the students and allow educators to increase their engagement in the learning process (Ballesteros et al., 2019). Project-based learning aims for the idea that students obtain a deeper learning and understanding of theoretical concepts through their application in real problems rather than just memorizing and applying these concepts in classic classroom problems. Problem-based learning technique allows them to relate these concepts with other subjects' knowledge and even abilities and real problems of their future profession. Problem-based learning technique has been used in some engineering programs as an alternative to support these concerns (Blumenfeld et al., 1991; Krajcik et al., 1994, 2003).

Particularly interesting for this study is the project-based learning model. The project-based learning method gives the students an assignment that, after performing a series of tasks, typically leads to the production of a final product: a formal written, an oral report or a design or model (Guo et al., 2020). The product is usually presented as a results of the project stated, the plausible solutions based on collated empirical evidence (e.g., through calculations or estimations), and the criteria used to select among them the most suitable solution.

Despite problem-based learning and project-based learning are similar in several respects, there are differences in the two approaches when being implemented. A project usually has a broader scope and may encompass several problems. While in problem-based learning the acquisition of new knowledge is more important than the final solution, in project-based learning, the emphasis is in the application or integration of the knowledge, rather than the acquisition of it. In project-based learning, the end product is the central focus of the assignment and the completion of the project primarily requires application of previously acquired knowledge (Prince and Felder, 2006).

Besides these teaching techniques, there exists flipped classroom and experience-based learning which can also deal with the pedagogical problems associated with teacher-centred approaches (Hao and Lee, 2016; Hussain et al., 2020). During the flipped classroom approach, course content is delivered to the students using a digital resource as pre-class homework, and the lecture time is used to construct knowledge through problem-solving either individually or in groups (Akçayır and Akçayır, 2018). Following this approach, classroom activity is shifted from teacher centric to student-oriented, and students starts the lab with prior information about what to expect from the class activity (Valero et al., 2018).

According to Prince and Felder (2006), the project-based learning is familiar in engineering education, having been used almost universally in laboratory courses. Also, most of the curriculum, including these courses, use laboratory work and practical work as principal features of undergraduate, and even graduate, degree programs in many engineering disciplines (Feisel and Rosa, 2005; Mahmoud et al., 2020; Burkholder et al., 2021; Reid et al., 2022). Laboratory work allows the students to get used to handling instruments and devices, as well as working in teams formed from people with different abilities and work methods. It offers hands-on experience that would reinforce concepts received in lectures and class assignments. This is the reason why the authors chose the lab sessions of the subjects to apply blended-learning strategy using both project-based learning and flipped classroom methodologies. The use of video clips as flipped classroom enhance the motivation and participation of engineering students in Mechanical design and Elasticity and Strength of Materials courses. Therefore, the objective was to improve learning outcomes and the acquisition of specific competences. The required competences/learning outcomes by the students are already listed in the official programmes of the Chemical and Mechanical Engineering Degree in each University. In the case of the Rey Juan Carlos University, the students studying these courses should develop transferable and specific competences. The transferable competences can be summarized as Problem-solving, Adaptation to new situations, Teamwork, Decision-making, Capacity to apply knowledge to practice, Creativity and Motivation for achievement. And the specific competences are Knowledge of fundamentals of Elasticty and Strength of Materials (for both Elasticty and Strength of Materials and Mechanical Design courses) and Knowledge of fundamentals of Theory of machines and mechanisms (also in Mechanical design course).

Over the years, the laboratory practices of *Elasticity and strength of materials* have been two: (1) thin vessel subjected to internal pressure and with strain gages located on the surface, and (2) flexural analysis of a three-point loaded beam. In order to design this new laboratory with inductive teaching methods and to make the lab-line more dynamic, 3D printing techniques and Digital Image Correlation DIC were going to be included in the activity. Then, it was decided to change the second laboratory practice of the beam loaded, as it was easier to model and manufacture using additive manufacturing and to measure deformations with videoextensometry.

Therefore, for this purpose, we have carried out a variation of the last classical lab practice to a design project (a project-based learning): the students have to design a bridge model, with prescribed boundary conditions, which must connect two points 30 cm apart, and which cannot deflect more than 5 mm with prescribed forces acting on the bridge. Students must design the structure, cross section of the bars or beams, and select the material they will use to manufacture it by additive manufacturing technique. To achieve the objective of the project, the students need to apply not only mechanical knowledge, but also logical reasoning indirectly linked to the customized environment.

The participation in these lab sessions means that students must develop transferable competences in a high extension, such as teamwork, decision-making, capacity to apply knowledge to practice, creativity, and motivation for achievement. This activity promotes the teamwork during the practical class but also outside, when students must work on the model. Moreover, they solve the design problem by working collaboratively as a team. They must take decisions to choose the best possible design and apply their creativity for different beam shapes and profiles. Also, the second core competence in knowledge of elasticity and strength of materials must be developed at its maximum level in order to achieve a good solution to the problem proposed.

During the lab sessions, lecturers and instructors supervise the correct progress of the activity. As far to the authors' knowledge, few project-based learning and flipped classroom activities have been implemented in mechanical and structural courses due to the high

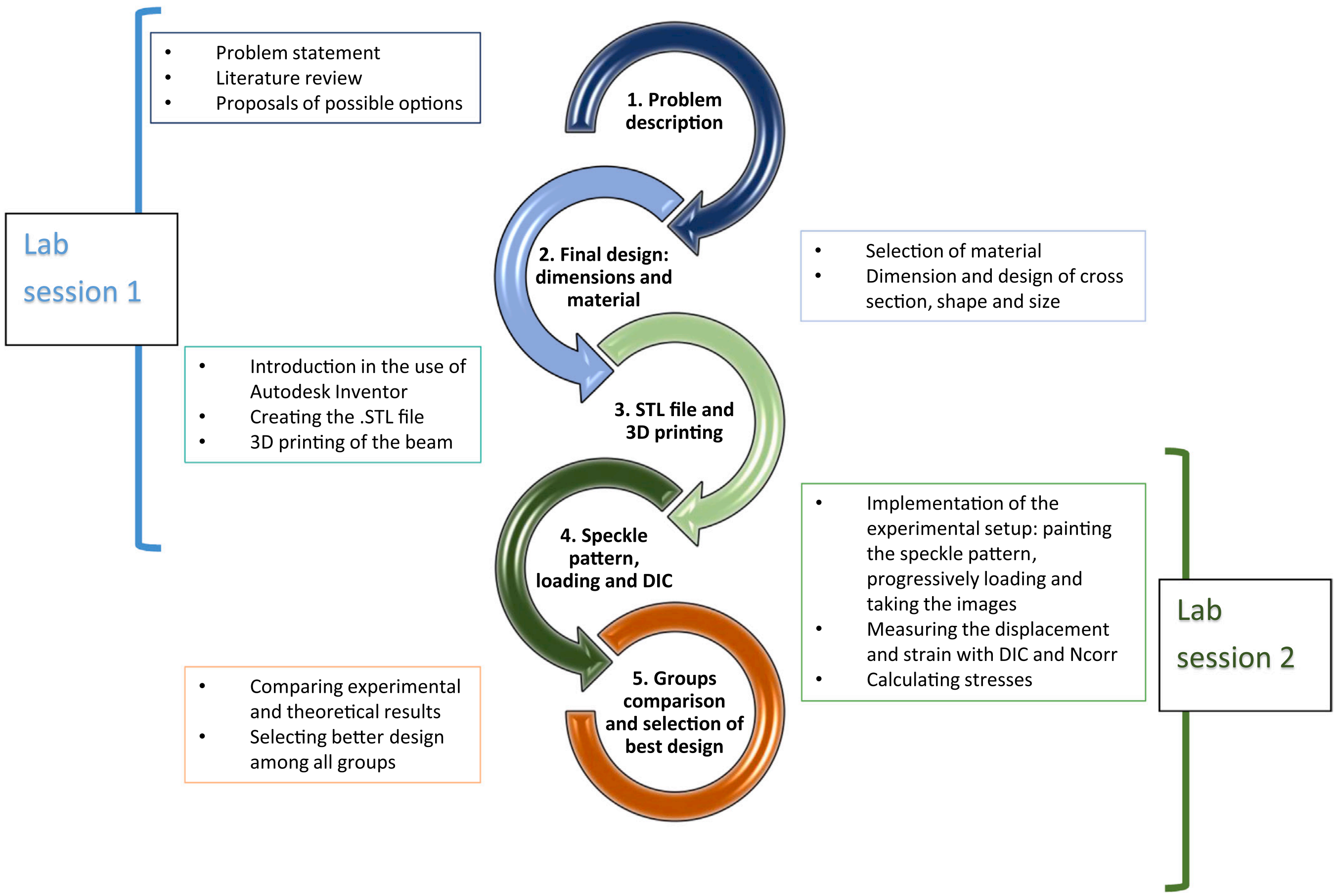

Fig. 1. Project-based learning laboratory: stages scheme.

difficulty of these disciplines and the full syllabus (Hussain et al., 2020; De la Flor López et al., 2016). We applied this methodology to two groups of students, which is a challenge concerning to the design and coordination of the activity.

2. Method and experimental setup

Learning in the laboratory is vital in many areas of engineering degrees, including mechanical subjects. Previous research has however shown that learning in the laboratory is sometimes not enough satisfactory as neither the theoretical nor the practical goals of learning proposed are reached. This section presents a new lab design, its implementation and assesment.

2.1. Pedagogical theory and educational context

There are different definitions of learning according to theorists, researchers, and practitioners. Nevertheless, a broadly accepted statement indicates that learning implies a change in human behavior, knowledge, skills, beliefs, and attitudes. Theoretical traditions have set four major learning theories: behaviorism, cognitivism, humanism, and constructivism (Schunk, 2012). Nonetheless, the literature shows that constructivism is the most popular learning theory in educational technology (Prince and Felder, 2006; Garzón et al., 2020).

The constructivism main idea is that knowledge is not transmitted from the teacher to the student, but is an active process of construction (Schunk, 2012). This is especially important in the context of engineering as practical knowledge is constructed on the basis of theoretical foundations (Taajamaa et al., 2018).

There are three main categories of constructivism: namely cognitive constructivism, social constructivism, and radical constructivism. Jean Piaget's theory stated the basis of cognitive constructivism, which focuses on how humans make meaning in relation to the interaction between their experiences and their ideas (Piaget and Cook, 1952). Social constructivism is based on the work of Lev Vygotsky, which stresses the fundamental role of social interaction in the development of cognition (Vygotsky, 1978). The last category, radical constructivism is based on the central idea that all knowledge is constructed rather than perceived through senses (Von Glasersfeld, 1974).

The project-based learning methodology has its basis in the constructivist learning theory, which claims that learning concentrates on interpreting and constructing meaning, and whose premises are: (1) knowledge is constructed; (2) prior knowledge is necessary and important in the learning process; (3) initial understanding is local, not global; and (4) building useful knowledge structures requires effortful and purposeful activity (Hein, 1991, Moreno et al., 2007, Sweller, 1988, Yilmaz, 2008).

The laboratory course presented in this paper, is developed as a project-based learning activity, and involves collaborative work and interaction among members in a group. Therefore, it is based on the pedagogical theory of Vygotsky constructivism (hands-on and experiential learning in groups with other students and the teacher), rather than in behaviorism (direct instruction) of typical engineering lab courses, in relation to the objectives and intended learning outcomes of the mechanical design laboratory.

Mechanical Design course is in the first semester of the 4th year of the Chemical Engineering Degree and *Elasticity and Strength of Materials* is taught in the first semester of the 3rd year of the Mechanical Engineering Degree at the Universidad Rey Juan Carlos (Madrid, Spain). Both subjects are assigned 6 ECTS, which is equivalent to 60-hour of in-person classes. In turn, the face-to-face teaching classes encompass 48-hour of lectures and practical classes and 12-hour of laboratory.

Each student attend three sessions of 4-hour practical lab. Each session has an instructor, who is responsible for the theoretical content and the teaching material. All the supporting teaching material and the videos can be accessed in the corresponding virtual space on Moodle.

The main learning outcomes of this course are, broadly, the ability to apply experimentally the fundamentals of elasticity and strength of materials (derived from a specific competence), the ability to apply engineering knowledge to practice (also derived from a cross-disciplinary competence) and the ability to produce correct oral communication (structured, clear and appropriate to the communicative situation) (derived from a core competence). The latter two competencies are also considered Generic Competencies in the Dublin Descriptors and refer to those competencies that are key, cross-disciplinary and transferrable to a wide variety of personal, social, academic and professional contexts throughout life. By acquiring these skills, on completion of the degree students will possess not only technical competencies but also methodological, human and social competencies (García-Aracil and Van der Velden, 2008; Villa, 2007).

The authors designed this project-based laboratory, based on the constructive learning model (such as inquiry-based or open-ended projects) as they can be very effective for higher level of learning outcomes such as design and life long learning, and develops student skills mentioned before (application of knowledge to practice, oral communication, critical thinking and problem-solving). The constructivist learning emphasizes that learning is the construction of knowledge on the basis of personal understanding and experience.

This learning model is particularly suitable for laboratory in chemical and mechanical engineering in which students are often required to integrate knowledge and experience from different courses to solve complex experimental problems.

2.2. Experimental procedure and project-based learning design

The main objective of this experience was to design, dimension and print a new bridge, and experimentally, determined displacements and deformations when loaded, using digital image correlation. The designed beam must have a constant cross section, based on some constraints (i.e. the size of both dimensions of the cross section, the thickness and the maximum displacement or deformation). The quality of deliverable product was evaluated by comparing the performance of all proposed designs created by the different student teams.

According to the work of Vallera (2019), the project-based learning must include the next stages: 1) teach content through knowledge and skills, 2) create a need to know important and fundamental content, 3) need critical thinking, problem-solving and collaboration, 4) develop investigation, 5) provide continuous feedback and 6) present or deliver the final product.

The activity was divided in the visualization of the videos and the lab classes. Fig. 1 summarizes the stages included in each lab session:

i. The educators prepare the videos with the information necessary and make them available at the Moodle virtual space for these subjects. This task is made before the lab sessions start.
ii. Lab session 1: the lecturers and instructors describe the problems in the lab: a model bridge must be fabricated to connect 2 points 30 cm apart. The bridge must be supported on a beam. The students will select a cross-section type and dimension it, considering a maximum deflection and prescribed loads. The students can use four different thermoplastic polymers: polylactic acid (PLA), polyamide (PA), polyacrylonitrile-butadiene-styrene (ABS) or thermoplastic polyurethane (TPU), and they must select one according to the dimensioning of their bridge.
iii. The students have ideation space and time within their group to consider different solutions, possible cross section and the material to select. Instructors will give feedback to the students based on literature review and exercises solved in classes, and using theoretical approximations.
iv. Once the group has designed the bridge and selected the material, the students draw it in the software Autodesk Inventor® (Autodesk, Inc, USA), the professor will help them in the learning of this software. They will also need to use BCN3D CURA (Stratos Solutions, Inc.) or Ultimaker CURA (Ultimaker, Inc.) to create the final file the printer uses. 3D Printing of the tangible bridge designed; using a Creality Ender 3 or a BCN3D Sigma R19 printer (Fig. 2).
v. Lab session 2: the structure has already been printed and next step is progressively loading the bridge with the prescribed loads and measuring the displacement and strains with digital image correlation technique. The students used a hanging weight with top hook of 0.5 kg and a set of 10 slotted weights that were added one by one. For these last two phases, the beam must be painted to have a dot pattern that the software Ncorr can follow in the video images. Comparison of the theoretical calculus with the results obtained experimentally. Ncorr is an open source 2D digital image correlation MATLAB® (Mathworks Inc.,) program.
vi. Present their design to the rest of the groups in the lab and decide which one is the best among all the teams.

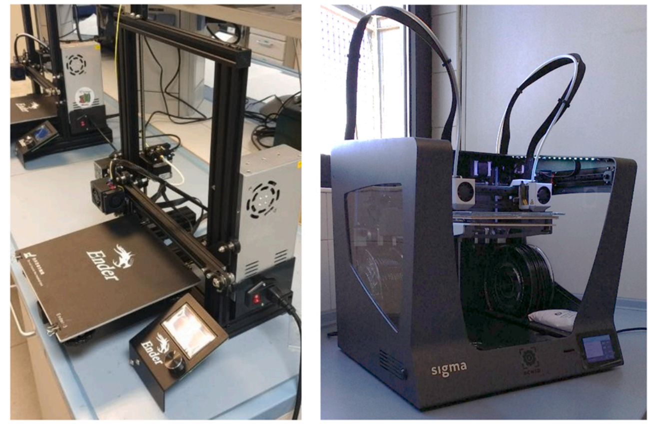

Fig. 2. Creality Ender 3 (left) and BCN3D Sigma R19 (right) printers available in the lab for 3D printing the beams.

The total number of students in each class is usually between 15 and 24. The recommended group size is four people in each group. There are two lecturers or professors in the lab and each one is in charge of 2 or 3 groups and they must meet the students' needs and questions. The total lab experience includes two sessions of 4 h each one, one class a week over 2 weeks.

The new laboratory was also assessed in terms of academic results in order to determine its effectiveness for the acquisition of competences and skills. The final lab exam comprises an objective test (50%) and one exercise related with the theoretical design of a structure (50%), giving similar data than in the design project of the lab. This exam evaluated the acquisition of the theoretical contents with the objective test and the acquisition of competences and skills with the design exercise.

3D printing:

Applications of 3D technology are numerous, and in recent years its use has grown exponentially in various fields, including teaching and research. "The increasing use of additive manufacturing and 3D printing is introducing the need to develop new skills and the opportunity to teach them in various subjects." (Ford and Minshall, 2019).

3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive processes. In an additive process, an object is created by laying down successive layers of material until the

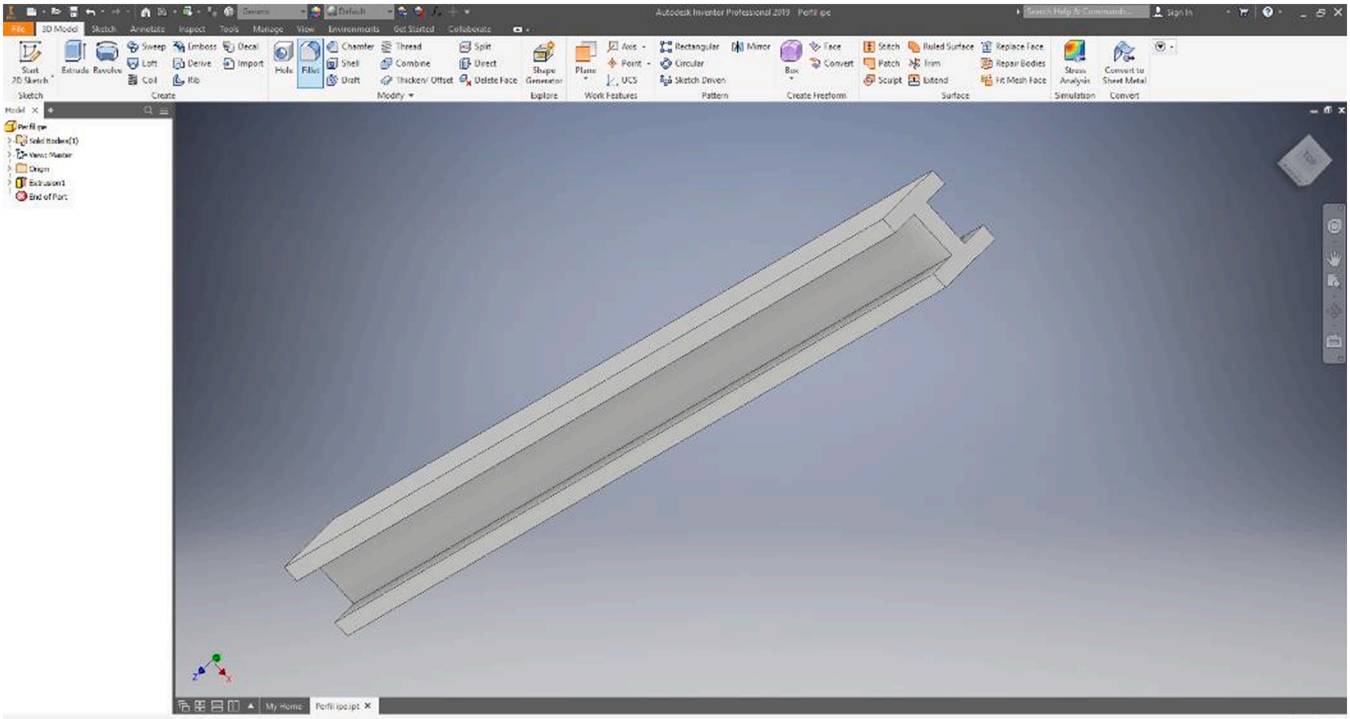

Fig. 3. Beam designed in Autodesk Inventor.

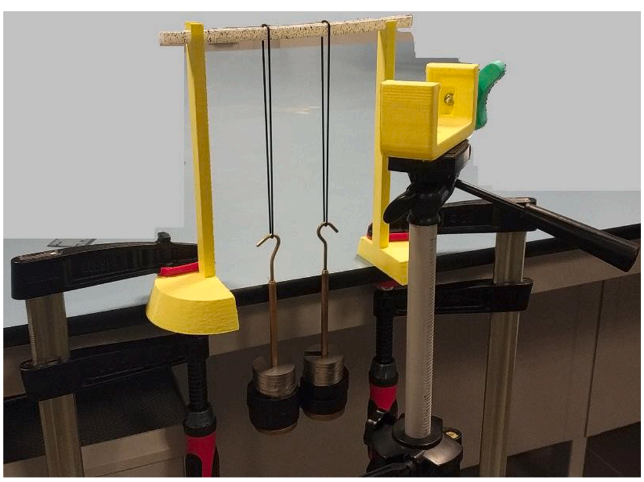

Fig. 4. Experimental set up: simply supported beam with two point loads.

object is created. Each of these layers can be seen as a thinly sliced cross-section of the object. 3D printing enables creating complex shapes using less material than traditional manufacturing methods.

We decided to use 3D printing to create the structure as an opportunity to fulfill industrial skills deficits in this emerging additive manufacturing and 3D printing technologies (Ford and Minshall, 2019). Chemical and Energy Engineering degrees do not usually have specific subjects that develop the additive manufacturing, and this the reason why the professors decided to include it in this new lab.

In order to 3D print an object, you need to have a 3D Model file. So, the students must become familiar with the file format.STL (Standard Tessellation Language or originally STereoLithography). STL files serve as an interface between your 3D model (CAD model) and the many 3D printers that are now available. STL is the common language in the 3D printing industry. The students used Autodesk Inventor for preparing their.STL file, but there are also other free programs to model.STL files, such as Tinkercad (Fig. 3).

The Mechanical lab has three Creality Ender 3 printers and one BCN3D printer that the students can used to make their models. These printers were already used to print the supports used in the experience when loading the beams (Fig. 4).

Videoextensometry:

Videoextensometry is a contactless technique for measuring strain based on DIC. It is an optical technique that compares images of a tested specimen surface to generate full field strain and displacement maps. It is mainly used in the field of mechanical and materials engineering, but it is also an emerging technique in Chemical engineering: dependence of size and shape of polymers on temperature or other environmental agents; or in measurements of deformations in pipelines, pressure vessels and reservoirs. New applications are constantly emerging. Compared to previous methods, such as the use of strain gauges, it possesses certain advantages such as the non-contact measurement and the possibility of measuring the whole displacement field and, consequently, deformations of any part (Peters and Ranson, 1982; Sutton et al., 1983; Wang, et al., 2005).

Progress in digital photography and computing extends the use of this technology, as it is also very cheap and easy to use. A simple mobile can be used to take the photographs and there is free DIC software to analyze experimental data, such as Ncorr, used in this lab activity (Blaber et al., 2015).

The overall goal of DIC is to obtain displacement and strain fields within a region of interest for a material sample undergoing deformation. DIC uses image processing techniques in an attempt to solve this problem. Basically, images of a sample are taken as it deforms; these images are used as inputs to Ncorr. The idea is to obtain a one-to-one correspondence between material points in the reference (initial undeformed picture) and current (subsequent deformed pictures) configurations. DIC takes small subsections of the reference image, called subsets, and determine their respective locations in the current configuration. For each subset, we obtain displacement and strain information through the transformation used to match the location of the subset in the current configuration. The result is a grid containing displacement and strain information with respect to the reference configuration, also

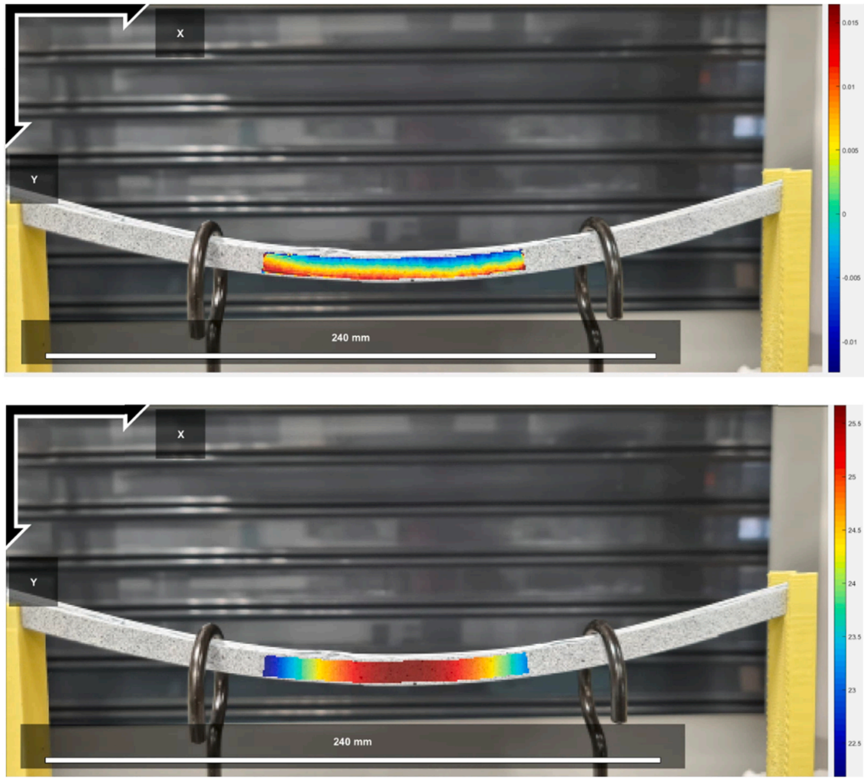

Fig. 5. *Ncorr* software showing vertical displacements v, (down) and longitudinal strains ε_{xx} (up) measured in the beam when being loaded.

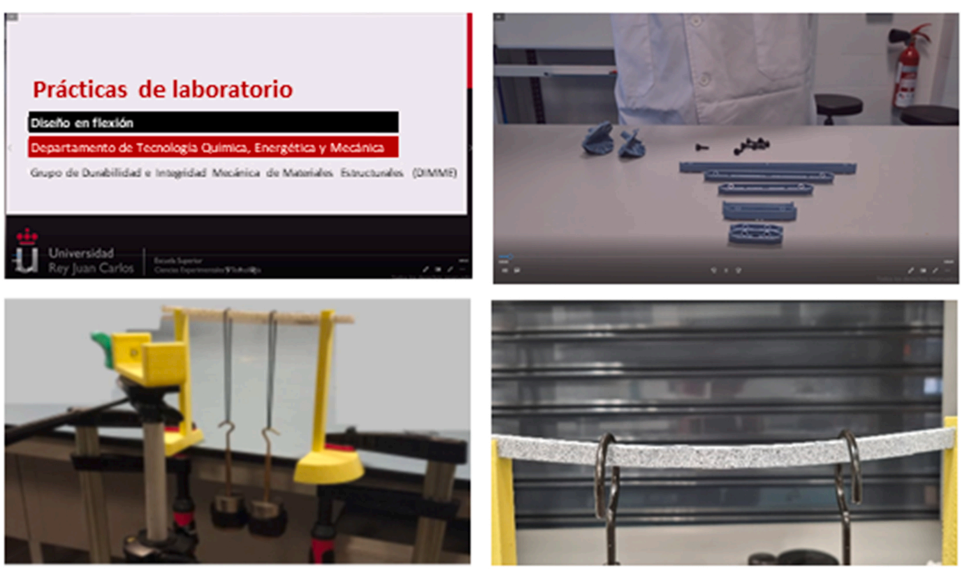

Fig. 6. Example slides from video clips: explanation, materials, developing.

referred to as Lagrangian displacements/strains.

In order to obtain these material points in the images, any visible marking can be used for pattern recognition, and these can be natural patterning on the specimen surface, pen marks, blob markers, punched gauge marks or a spray paint speckle pattern. The pattern recognition algorithms work on identification of unique small facets in the video image. The students have three options to have the speckle pattern: 1) black spray paint, 2) airbrush for a more regular pattern or 3) pen marks.

As a summary, with this method it is possible to know displacements and deformations in loaded parts, painting these pieces with a white background and painting a pattern of black dots on the white background, then taking several photos during the process of loading the part, and analyzing these images with digital image correlation software (Fig. 5).

2.3. Video-clips

Our challenge was to improve the learning method by changing from a model that simply presents the practical sessions to a model that actively involves students in the learning process. We aim to convert our educational model to a “user-centered” model that places the students at the center of the learning process and empowers them to guide their own

Table 1
Ten questions to students about the lab and its effectiveness.

Question	Detail	Multiple options
Q1 Q2	Which part was the easiest for you? Which part was the most difficult for you?	a) Dimensioning the bridge b) Material selection c) Preparing the STL file d) Using the 3D printer e) Loading and taking pictures f) Speckle pattern and DIC
Q3 Q4 Q5 Q6 Q7 Q8	I am very satisfied with this activity I am very satisfied with the learning gained I am very satisfied with the resources and quality of the information and video clips available to carry out the experience I consider this methodology in the lab is more suitable than the traditional lecture for me I felt comfortable working in groups and selecting the final design all together I consider this learning approach has helped me to grasp the theoretical fundamentals of the subject	a) 6 - Strongly agree b) 5 - Agree c) Slightly agree d) Slightly disagree e) - Disagree f) 1 - Strongly disagree
Q9	Has this activity motivated you to study the subject?	a) Sure, I wanted to do a good job b) Yes, but just a little c) No
Q10	Would you recommend this activity to other students?	a) Sure, I liked it a lot b) Probably c) Maybe d) No

educational experience. So, some days prior to the lab sessions, the assistant professor records video clips explaining the lab theoretical basis, safety requirements and the session procedure.

Video clips to enhance the learning experience has been included (Fig. 6). The flipped classroom is based on *learning by watching.* This is a significant improvement to the subject; it has also required a lot of time and dedication to prepare. For each practical session, we have prepared a 15 min illustrative video, which presents the fundamental aspects (overall objectives, operational objectives, key ideas, conclusions, etc.). The videos are intended to help students summarize each practical session for the lab session.

2.4. Assessment of learning outcomes

The assessment was conducted with our 4th and 3rd year cohort taking the Mechanical design and Elasticity and Strength of Materials courses in the 2020/2021 academic year.

The academic results were analyzed for a total of 145 students. The average age of participants was 21 years (age interval 20–23 years). The gender distribution was male (73,8%) and female (26,2%).

The lab sessions were developed according to scheme in Fig. 1 without incident. The instructors were ready to solve questions and collaborate with the students, providing feedback and constructive comments prior to the start of any subsequent task, before, during and after the lab sessions. This formative comments and feedback was intended to give students a chance to reflect on their work, and critically review and iterate their design solutions. As such, the assessment of the project-based laboratory involves more scheduled interactions and timely feedback between students and instructors.

For quality assurance and assessment of the learning outcomes, students' perceptions and satisfaction with the new project-based learning lab, a survey was conducted via Moodle, containing ten questions divided into three main categories (Table 1):

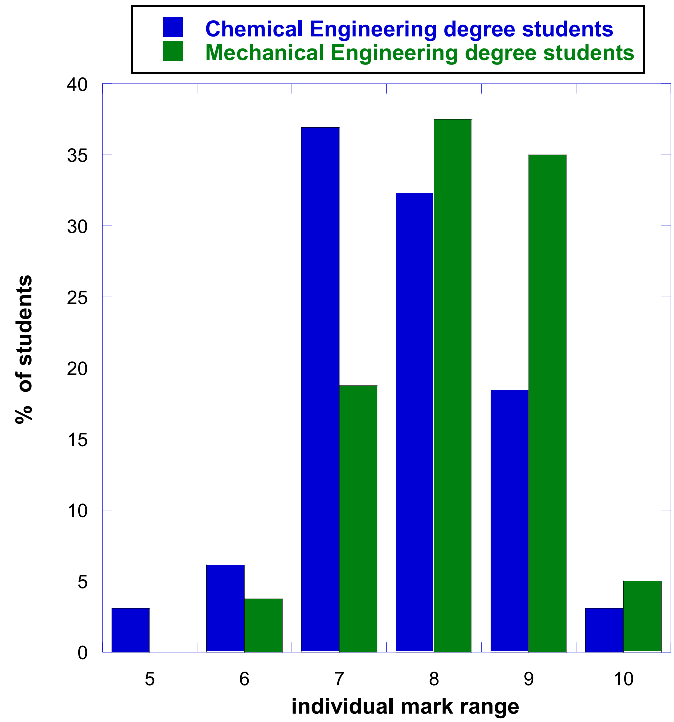

Fig. 7. Grade distribution of Chemical and Mechanical engineering degrees students.

- Questions 1 and 2, with closed-answer text to analyze which part of the lab was the most difficult and easiest for students.
- Questions 3–8, related to rating the usefulness of the improvements for better understanding the overall subject, and their usefulness for preparing the exam and regarding the video clips and self assessment methods for achieving the main learning outcomes. A modified 6-point Likert scale was used (a) strongly agree, b) agree, c) slightly agree, d) slightly disagree, e) disagree, and f) strongly disagree. We have used a six-point Likert scale in order to avoid a neutral response which is difficult to comprehend and differentiate with a case where someone is not interested in participating. This type of statement aligned well with specific learning outcomes and lab objectives, and has been considered to be effective in assessing the learning outcomes.
- Questions 9 and 10, closed questions (yes/no/probably) related to overall satisfaction with the activity and their learning outcomes.

The results of one academic year have been analyzed, where the average participation on the surveys was 92%. With these data, it is possible to assure that the average data represents the whole student community that participated in the lab activity.

The data collected from the survey were statistical analyzed for each question posed. Percentages of answers were calculated for all the 10 questions in the questionarie and a box-plot was constructed for questions 3–8. To measure the results of the learning outcomes and competences with the implementation of this interactive teaching system, the students' final grades for the lab course were also studied.

3. Students' survey results and discussion

Fig. 7 shows the grade distribution of the cohort of 145 students for the project based learning laboratory for both degrees. The median grades for the lab in both Mechanical and Chemical engineering degree were very similar (8.18% and 7.66%, respectively). Although the mechanical had slightly higher class average grade (8.18%) than the chemical (7.66%), the last one has greater standard deviation (1.04)

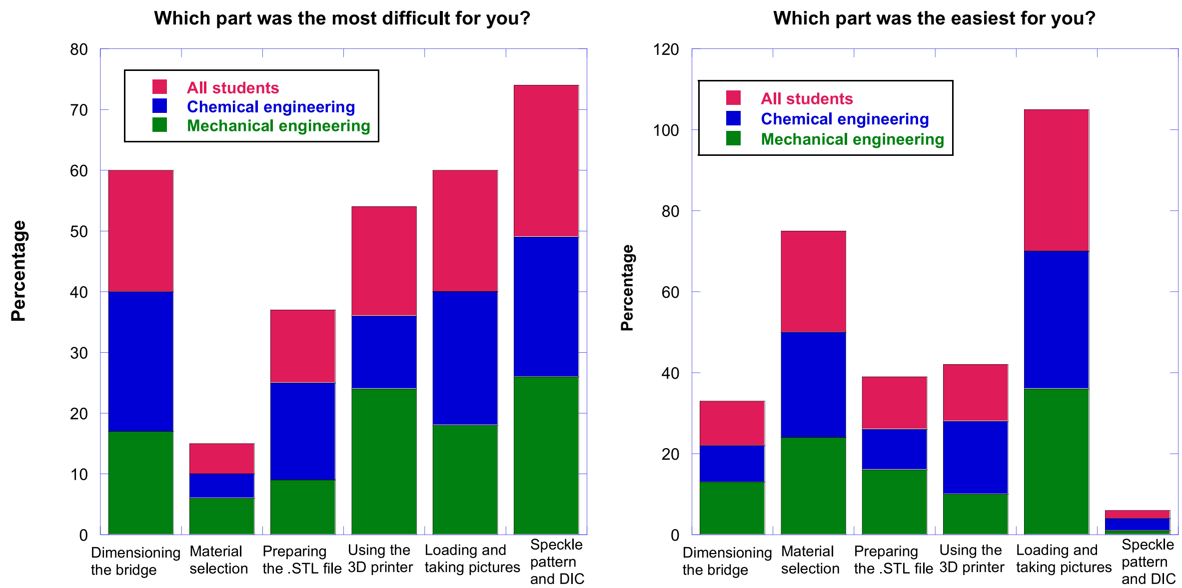

Fig. 8. Results of the question Q1 and Q2 of the survey taken by students involved in the lab activity. These questions show the part of the lab sessions that the students found the most and the easiest activity in the project.

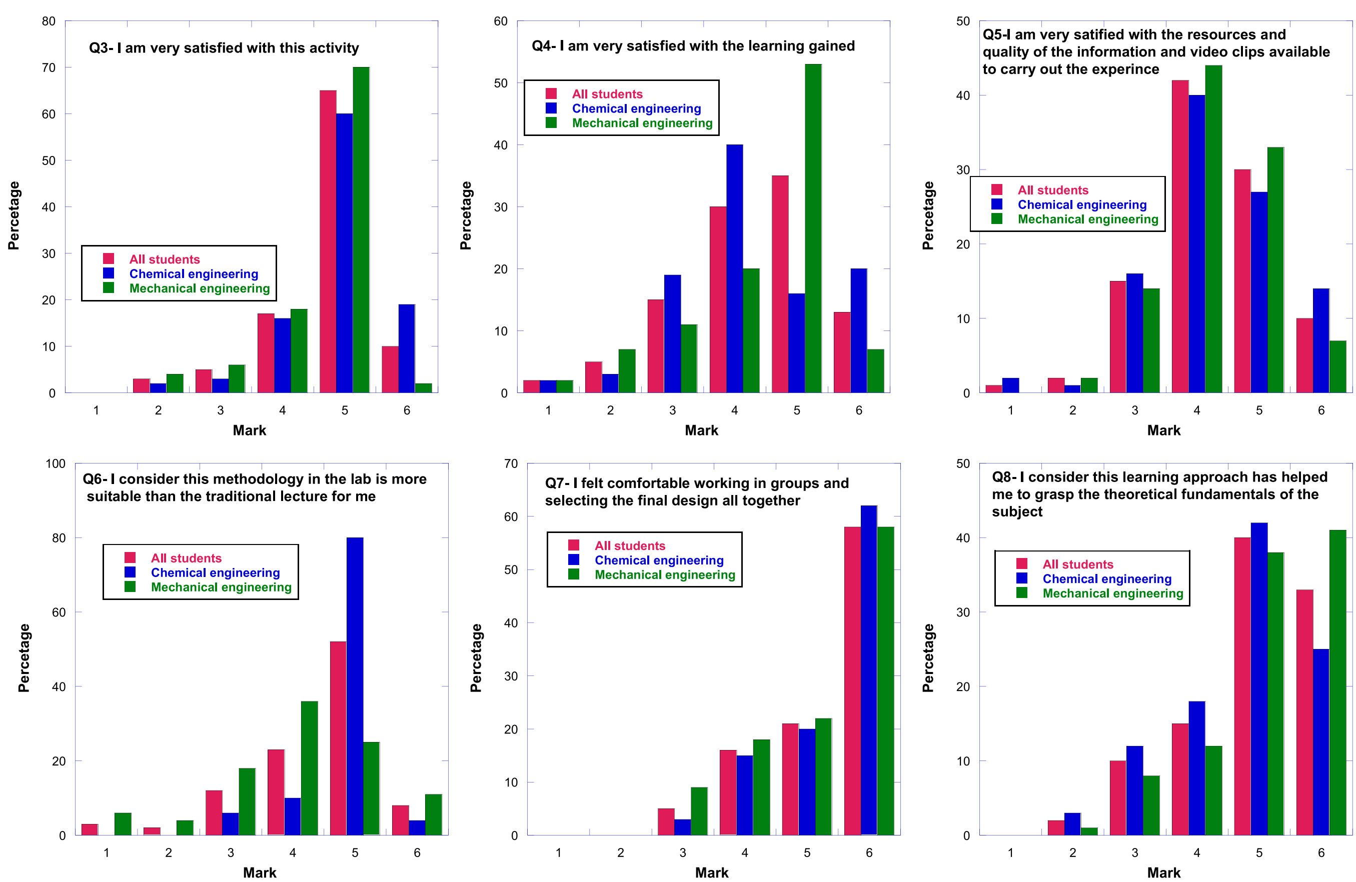

Fig. 9. Results of the survey taken by students involved in the lab activity. Each statement had five answering options with an assigned numerical value, being 6 the maximum mark and 1 the minimum. This type of statement aligned well with specific learning outcomes and lab objectives has been considered to be effective in assessing the learning outcomes. The results are shown for all the students together and also distributed by degree.

compared to the first (0.92).

The feedback from students was obtained from the survey results. The survey consisted of 10 different questions related with three aspects of the lab activity: learning outcomes (competences acquired), student satisfaction with the experience and difficulties found in the lab development.

Fig. 8 shows the results obtained on the students responses to the questions in the survey related with the most difficult and easiest part of the lab activity. Based on the data collected in the survey it is possible to assure that most of the students thought the easiest step in the project-

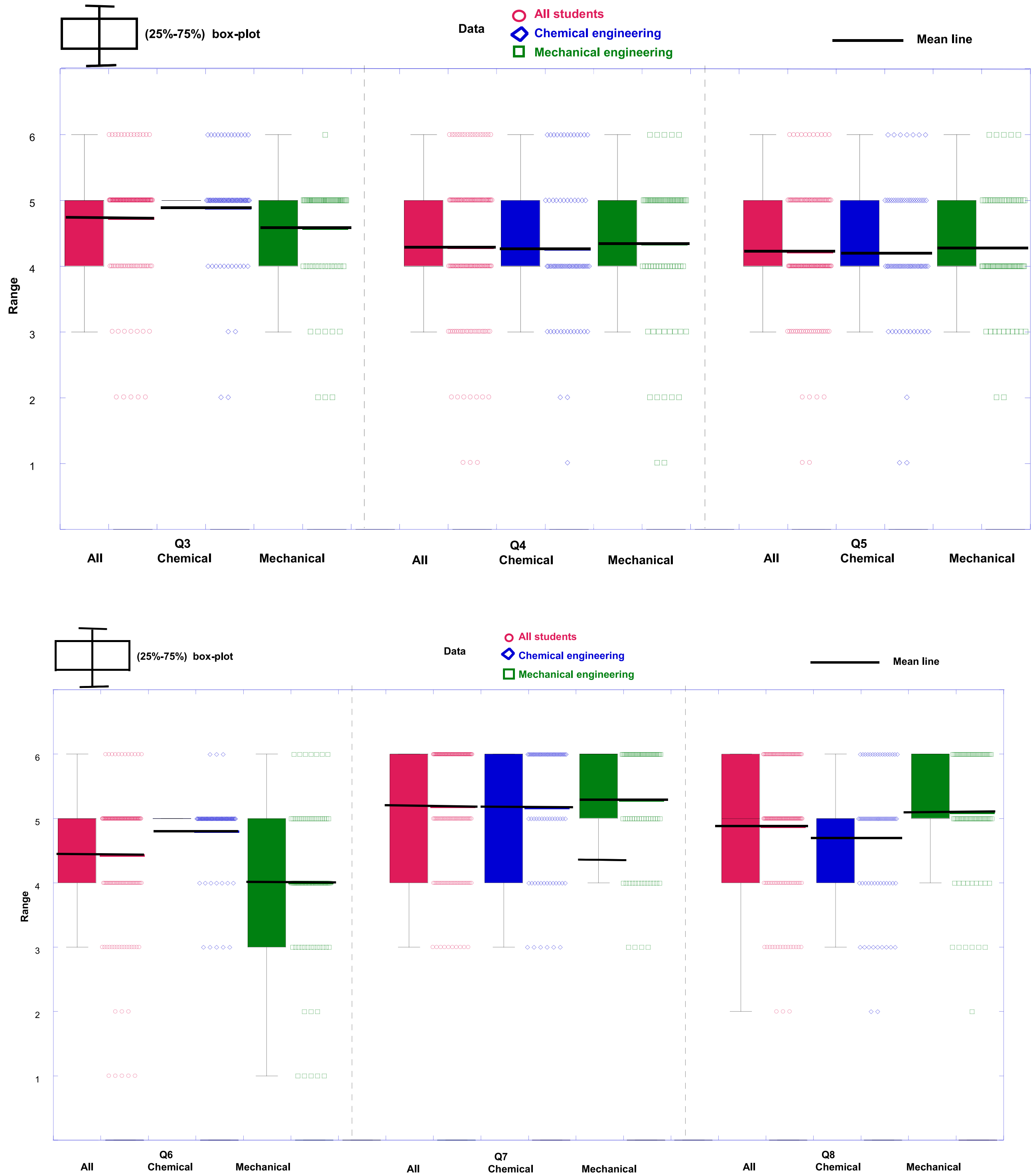

Fig. 10. Box-plot with the results of the questions Q3 to Q8 of the survey taken by students involved in the lab activity. All the data are also shown in the graphs.

based learning activity was loading and taking the pictures, but the more difficult was to analyze the data obtained. This last item was similar in difficulty as the first one, selecting the material and dimensioning, which is directly related to the specific competence of these subjects.

Fig. 9 shows the students answers to six statements and questions concerning level of satisfaction with the whole activity, the learning gained, working in groups and collaborating. Each statement had five answering options with an assigned numerical value, being 6 the maximum mark and 1 the minimum. This type of statement aligned well with specific learning outcomes and lab objectives has been considered to be effective in assessing the learning outcomes. Most of the students supports the project-based learning in the lab sessions is a correct way to improve the subject knowledge and this activity has promoted team work and the students felt comfortable with that way of working. The activity has achieved a total cooperation not only between students inside one group, but also between groups, necessary to achieve the final goal proposed in the activity. Also, students answered that video clips were useful resource for understanding the lab sessions. These data therefore support our hypothesis that the resources help students achieve two of the main learning outcomes: the specific competence, in the

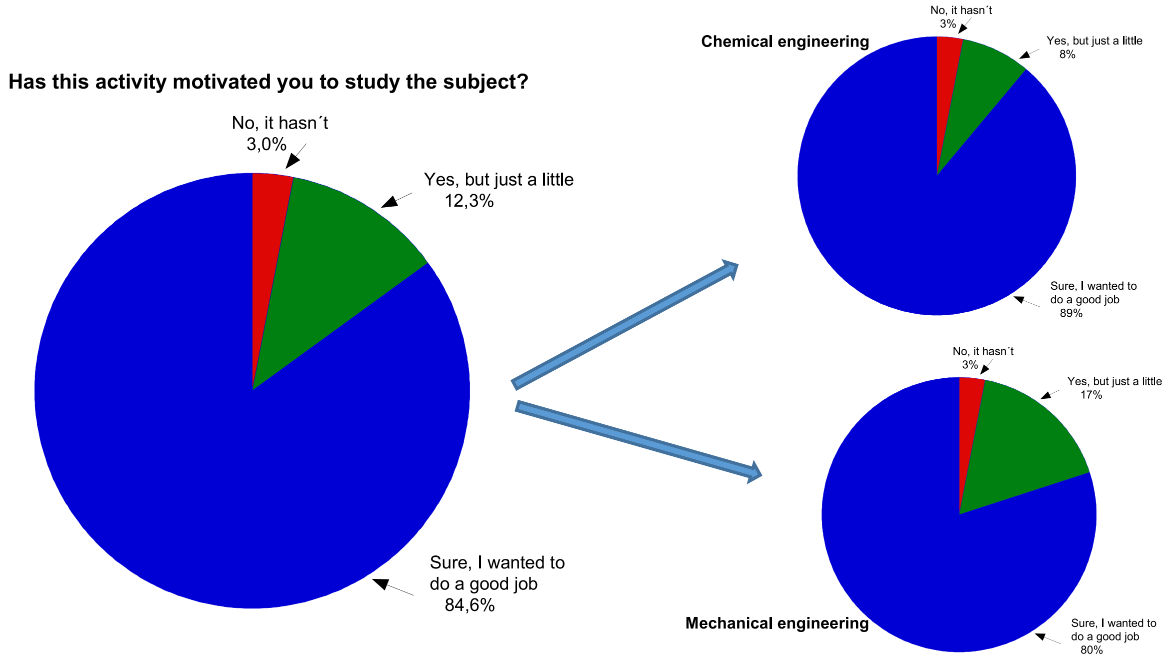

Fig. 11. Results of the question Q9 in the survey taken by students who took part in the lab activity: on the left, results for all the students together, and on the right, results separated by degree.

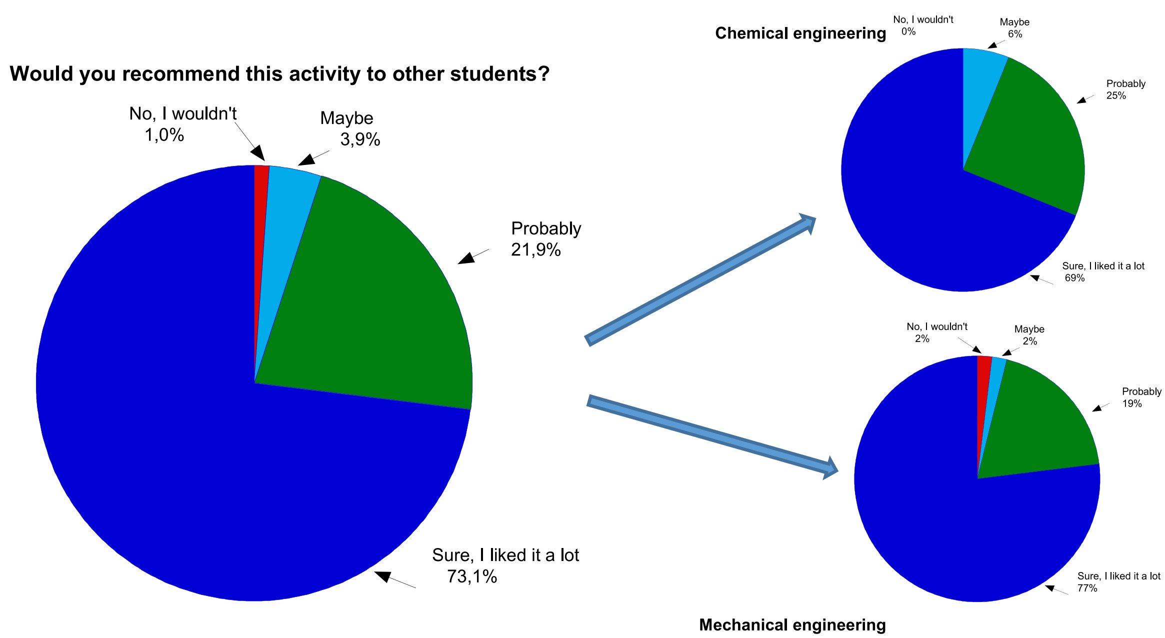

Fig. 12. Results of the question Q10 in the survey taken by students who took part in the lab activity: on the left, results for all the students together, and on the right, results separated by degree.

case of video clips; and the core competence, in the case of the self assessment methods.

The results obtained in these 3–8 questions, have been statistically analyze making a box-plot with the data for these questions (Fig. 10). This figure shows the answers divided by degree and all students together. This plot provides a useful way to visualise the range of responses and the distributional characteristics of each group. These results in Fig. 10, suggest that all students perceive themselves as very satisfied with the activity. Moreover, Chemical engineers showed higher values than Mechanical ones.

The perception of the resources used and about the video clips was also good, and very similar for both degrees, which means it was correctly adapted for each group.

Directly related to question 3, about their satisfaction with the activity, answers to question 6, show that Chemical engineers considered this methodology in the lab more suitable than the traditional lecture for them compared to the Mechanical students. Finally, in their assessment of the learning approach, students found the activity has helped them to grasp the fundamentals of the subject. Although, this time, Mechanical students mean value was higher than for the Chemical alumni.

Fig. 11, shows the results of the two final questions of the survey taken by the students. Because of this learning process, students often had a better understanding of the relationship among the design, lab experiment, and underlying theory before they actually performed the project, which leads to about 85% more students who believed this activity has motivated them to study more the subject and will recommend it to new students. Fig. 12.

Authors also observed that students were comfortable using design heuristics from their lecture courses to evaluate their design solution. But they were also reminded to use experimental observations and results to justify their design and the election of the final better one. This added another dimension of the hands-on lab experiment to student overall project. This method, involving instruction and students-centered learning, emphasizing the roles of the hands-on experiments in both design and experimental and real life activities, has been found to be effective in promoting high-level learning outcomes in laboratory environment in other open-ended or constructivist learning methods (Zhang et al., 2020).

The evidences of this study suggest that this new lab with the incorporation of authentic design can greatly enhance high-level learning outcomes and high-level engineering skills. This project-based learning activity is more effective and satisfactory to student learning as it motivates individually each student to study the subject, to complete the tasks and promotes the collaborative work between the participants to reach the final objective. Due to all these factors, we can confirm that the activity has reached the goals it was designed for: motivating students to an active participation and study the subject and grasping new skills in innovative techniques such as 3D printing and DIC.

4. Conclusions

In conclusion, the educational methodologies applied in the laboratory gave the students a different approach to one of their major courses (Mechanical Design and Elasticity and Strength of Materials) in the last years of their engineering degree. The proposed project-based learning had the ability to help integrating the knowledge and improve the skills included in the main competences of one the most time-consuming and difficult subjects of the engineering program. This lab activity provided the students with various challenges: linking all the subject knowledge with the new acquired in the lab, solving the driving question, creating a 3D printed product and analyzing the displacements and strains using DIC. The project-based learning laboratory provided the students with new tools in managing mechanical problems, and they answered positively on the benefits that the project-based learning contributed to their final knowledge in the subject.

Moreover, online video clips for teaching and learning, combined with other interactive techniques (selfassessment methods and enhanced teaching material) are effective tools for supporting learning outcomes. The students' final grades were quite good, therefore, these resources have significantly helped and supported student grades. Moreover, the degree of student satisfaction, ascertained through the survey, is noticeably high, so it can be concluded that the new laboratory, with active learning methodologies, has been well received. The students consider the new resources to be very useful both for understanding the overall subject and for preparing for the exam.

The lab proposed based on a project-based learning with a design component is considered as very challenging due to its open-ended nature and requirement of students integrating pilot-scale lab with relevant design. This could be mainly due to the sequential instruction and formative assessment for the project-based learning that was able to provide students with timely feedback for them to continue to improve. The results analysis showed that all students perceive themselves as very satisfied with the activity, and that they considered the resources and video clips used has helped them to understand the theoretical fundamentals of the subject.

These results are encouraging, although considering all the survey, there are still parts of the lab activity that should be improve in order to make the activity less time consuming and the most difficult part being easier for the students. The same activity could be implemented in the same subject in other different degrees and editions in order to have more data and compare them.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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