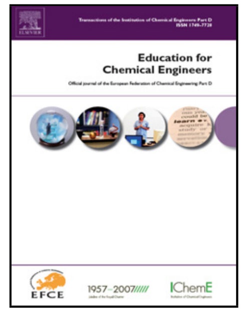

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INTEGRATION OF DIFFERENT ASSESSMENT APPROACHES: APPLICATION TO A PROJECT BASED LEARNING ENGINEERING COURSE

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Highlights

- Integration of different assessment methods in a chemical process design course
- Improve student learning process by active participation of the students in rubrics
- Formative assessment, self-, peer and co-evaluation as valuable learning processes
- Positive student perception about the evaluation strategy after two academic years

Abstract

Formative assessment and self-, peer- and co-evaluation strategies for assessing students' learning have been developed and applied, over two academic years, to 75 students on a project-based learning course in the Chemical Engineering Degree at Cantabria University (Spain). The project proposed for teamwork learning in the Process Design course was the preliminary design of a second-generation bioethanol plant. Rubrics of formative assessment and evaluation generated positive reinforcement for the student advancing through the consecutive learning stages. The negotiated co-evaluation process has proved to be an effective tool for reflecting the distinctive contributions of each working group member, which are then successfully incorporated in the final individual mark set by the teachers. Students' perceptions regarding the proposed assessment approaches have been obtained by

creating and applying an anonymous and voluntary survey instrument. The active participation of the students in the design and application of rubrics using specific criteria is proposed for peer-assessment processes in learning activities with high qualitative content and more susceptible to subjective capabilities such as oral presentations. We consider that the assessment, learning methodology and the experience gained with the survey results contribute to enhanced achievement of the learning outcomes, and to enhanced quality in the teaching-learning process.

Keywords: Chemical process design, Assessment task design, Formative and summative assessment, Teamwork, Co-evaluation.

1. Introduction

Constructive alignment is a systemic teaching strategy that guides decision making at all stages of instructional design. Components such intended learning outcomes deriving at a high cognitive level, teaching/learning activities to obtain those objectives and assessment tasks and their grading to evaluate performance of the students, must be aligned while maintaining the constructivist view of an active learning (Biggs, 1996; Biggs and Tang, 2011). In an active-learning approach in higher education, activities should be designed with the focus on learning outcomes, promoting student reflection, and getting students to think about what they are learning (Prince, 2004). The most notable gains from the use of active and collaborative teaching methods have been found in students' conceptual learning (Butterfield et al., 2015); these methods can help students develop a deeper understanding of principles underlying the subject studied. General and specific active and collaborative learning approaches, such as project-based learning (PBL) and others, have been developed for core courses in engineering and chemical engineering (Biegler et al., 2010; Delgado and Fonseca-Mora, 2010; Hanney, 2018).

In contrast with more rigid assignments, where there often is only one correct answer to each problem that may limit deep learning and creativity (Osen and Bye, 2018), the project-based learning designed as an open-ended project, working with limited information and where many different approaches can lead to successful completion is strongly recommended to a Chemical Process Design course.

PBL allows to the alignment and the development of transferable critical analysis skills and facilitate deeper learning as the students are effectively self-monitoring and self-regulating themselves in relation to the scope, scheduling and responsibility for group tasks. In addition, the use of PBL and new methods of assessment, including peer assessment methods, in early years of a chemical engineering degree, it has been shown that facilitating students' utilisation and integration of knowledge gained during their studies and support students undertaking Chemical Engineering Design during the latter years (Fletcher and Boon, 2013). Project-based Learning (PBL) is a teaching methodology that has demonstrated improvements in learning outcomes, in comparison with traditional teaching practices, based on lectures and practical exercises, in which students are merely the passive receptors of information. In contrast, PBL places students at the centre of teaching and learning activities and, within the specific context, encourages them to put into practice the theoretical scientific knowledge they acquire. Other benefits of PBL are that it encourages students to develop balanced yet diverse approaches to solving real-world problems, both on their own and in a team; students get to understand the relevance of the information to be learned; they are helped to learn information in the same way that it will be used in practice; PBL promotes the transfer of learning, and enhances the generation and retention of knowledge. Compared to traditional teaching methodologies, in PBL students develop transversal competencies and valuable skills in the performance of the project work; the abilities learned include problem definition and solution, data collection and analysis, collaboration among team members, scientific communication, public speaking skills, and understanding how to develop a topic (English and Kitsantas, 2013; Hoffman et al., 2006; Moreno-Ruiz et al., 2019; Robinson, 2013)

PBL requires students and teachers to monitor, reflect on, assess and update their practices continuously, because it is a learning process that cannot be fully predetermined (Chounta et al., 2017). New active learning techniques require appropriate methods of assessment, such as portfolios, rubrics, written and oral presentations, surveys, interviews and focus groups, conversational analysis, observation and meta-analysis, among other possible options that may routinely be used for engineering education (Libman, 2010; Wankat and Bullard 2016). In all cases, assessment should be linked to the learning objectives of the course. Alignment of learning objectives, learning methods and assessment is fundamental in higher education (Tuunila and Pulkkinen, 2015). The constructive alignment of teaching and assessment in the curriculum is presented by Biggs (2003) as "an assessment system that tells you how well each individual student's assessed performance matches what is required" and problem-based learning has been given as an example of aligned teaching. Constructive alignment can be integrated into teaching and assessment if the objectives are clearly stated and if students' performance is linked with those objectives (Biggs 1996, Biggs and Tang, 2011). Alignment of assessments with learning objectives increases the likelihood that the instructors will be able to give students the opportunities to learn and practice the knowledge and skills that will be required in the various assessments designed. In addition, "good grades" are more likely to translate into "good learning" by focusing student efforts on learning (CMU, 2020).

A course designed under a constructivist perspective need to specify the level of understanding intended of the designed learning outcomes, need for introducing a range of teaching/learning activities and implicates the use of an assessment portfolio where the students select at least some of the evidence that they consider matches the learning outcomes; this further implicates the use of self- and peer-assessment (Biggs, 1996). The relevant literature confirms the desirability of using a diverse combination of assessment methods within an active learning approach (Lynam and Cachia, 2018). This combination of delivery and assessment methods is being recognised as a key part of active learning, providing opportunities for students of all levels to learn and to develop transferable skills (Langrish and See 2008). The review of Day et al. (2018) shows that the use of different assessment methods influences students´ grades, and helps them to achieve educational learning goals more easily and to perform better.

Different strategies for assessing students' learning (Felder et al., 2000) can involve assessments that are formal or informal, high- or low- stakes, anonymous or public, individual or collective. All of these types of assessment should include rubrics that will make assessment criteria clear and that facilitate more successful learning (Delgado and Fonseca-Mora, 2010).

Formative assessment refers to the gathering of information or data about student learning during a course or programme, that is used to guide improvements in teaching and learning; the object of this approach is to help students develop self-awareness, self-control and strengthen their learning in relation to the desired study outcomes of the course syllabus or curriculum (Hassan, 2011). In addition, formative assessment not only allows the verification and grading of the process; but is also an element of learning process improvement, and an aid for both teachers and students (Castejón et al., 2015). The feedback process in this assessment approach is critical for effective learning, and is a key component of effective practice, by giving learners repeated opportunities to incorporate that feedback in their learning process; in addition, it has a direct impact on the professional development of the teacher because it encourages informed reflection on the teacher's own practice, and hence stimulates innovation (Boud and Molloy 2013; Day et al. 2018; Wallin et al. 2019).

Student Peer-Assessment, whereby students assess each other's work, has been extensively reviewed by Evans (2013) and Vickerman (2009), with recent findings specifically for chemical engineering cohorts (Davey, 2015). Student Self-Assessment is defined by Boud (1995) as "the involvement of students in identifying standards and/or criteria to apply to their work, and making judgements about the extent to which they have met these criteria and standards". Peer- and self- assessment methods are most commonly used for assessing team performance; these approaches train students to work in teams, to rate teamwork skills, and make student team meetings more effective. Training students in these skills will improve the performance of teams in cooperative learning and problem-based learning. Peer- and self-assessment activities reinforce abilities for the constructive reflection on both teaching and learning that is essential for working effectively as part of a team. The integration of self- and/or peer-assessment within overall assessment will effectively encourage the involvement of students with their learning, increase their motivation and incentives, and give them some sense of responsibility for the running of the unit of study (Langrish and See, 2008). Published studies reveal the benefits and limitations of self-, peer-, and teacher assessment methods in higher education, as well as the different scoring results obtained using these methods. However, the relative effectiveness of each assessment approach applied needs careful and specific analysis, because the assessment process is conditioned by many factors (Chen 2010; McGarr and Clifford 2013; Evans 2013).

The quality of teamwork demonstrated in a PBL approach is very often criticised as being inequitable when the same assessment score is attributed to all group members irrespective of the contribution or effort each individual member of the group has made (Cheng and Warren, 2000; Raban and Litchfield, 2007). One way to overcome this potential disadvantage is to involve students actively and purposefully in assessing the contributions of their peers in the process of group work by various scoring methods in a procedure that is either negotiated with students (Planas-Lladó et al., 2018) or applied by teachers on a confidential basis (Ko, 2014). A co-evaluation process like this additionally can contribute to enhancing relationships within and between working groups, and to promoting skills for the future professional needs of students. Self- and peer-assessment are vital for improving students' skills in teamwork, in both formative and summative situations; however, Sridharan et al. (2019) suggest that a disadvantage of using a summative assessment in collaborative group assessment is that, objective judgement is inhibited when some students are reluctant to assess their peers honestly, since they realise that their actions could penalise fellow-students who contribute less.

The Spanish university regulations leave to the department or faculty decisions on the application of particular assessment methods, and these decisions tend to fall to teachers to make. The implementation in the university sphere of formative assessment methodologies has been gradual and they have not been applied in a very consistent or thorough manner in Spain due to a lack of favourable institutional policies (Panadero et al., 2019; Planas-Lladó et al., 2018).

In the University of Cantabria the assessment approaches being applied in engineering studies are still traditional; the one-time examination is the method most used, and students' involvement in assessment and grading has been extremely limited (Galan et al., 2016).

However, in the strategic framework set out in the European Cooperation in Education and Training 2020 Proposals (EC, 2009) student-centred learning in higher education is promoted; this approach to education is characterized by innovative methods of teaching, including different types of assessment, that aim to involve students as active participants in their own learning. In this context, it is necessary to manage the pressures exerted by the education system for the design and application of various different approaches to evaluation, taking into account the complex contexts in which student performance is conditioned by the individual options chosen by the student and the social relationships affecting the teaching and learning processes.

The motivation of this work is to show a Chemical Process Design course designed under Bigg's constructive alignment with special emphasis on the use of different assessment approaches and how students perceive these methods, as a process of continuous improvement in the achievement of expected learning outcomes. The aim of this study is to report and analyse the results of the development and the integrated application of assessment tools comprising formative assessment, self-, peer- and co-evaluation, in a formative and summative way, to a creative subject (Chemical Process Design) part of an engineering degree course, over two academic years (2017-2018 and 2018-2019). The students' perceptions regarding the diverse assessment methods proposed have been obtained using students' responses to a specially-devised survey instrument applied anonymously and voluntarily. The empirical data obtained in this individual study and reported in this article may help improve quality in the teaching-learning process. It is hoped that it will serve as an incentive for other teachers to engage in such dynamics; and that it may be useful for the design of future institutional actions, especially in a context of education where previous initiatives in this field are limited.

2. Application of Project-Based Learning and Different Assessments

Project-Based Learning (PBL) was selected as learning approach because it adapted the characteristics of the subject, in which prior knowledge is applied to a real-life engineering design experience (Aranzabal et al., 2019; Woods, 2012). Working in groups under a PBL approach is specifically emphasized to promote a process of collaborative learning that is regarded as essential for professionally-oriented educational programs (Du et al, 2020). Furthermore, it is a perfect complement to the inverted classroom method used for the theoretical concepts of the subject, and allow students to develop a series of transversal competences and valuable skills, outcomes of the subject, as teamwork, decision making, screening alternatives, or oral and written communication.

To explore issues regarding the application of different assessment methods and tools for engineering students involved in the relatively-creative discipline of Chemical Process Design, we have adopted the following methods, that combine objective and subjective data obtained from teachers and students, with a view to presenting this recent shared scholarly experience that the authors consider has been useful to them and their students. This section describes the characteristics of the main course of study, the motivation for undertaking the project, and the management of the PBL approach applied.

2.1 **Project set for PBL, and Chemical Engineering course background**

The course project selected for the students was the production of second-generation bioethanol from lignocellulosic biomass via hydrolysis to meet a specific demand. The base case of this project is taken from the process design case studies of Martín and Grossmann, 2011a, b. The reason for selecting this project is the interest in obtaining more environmentally-friendly fuels by means of the preliminary design of real industrial processes. Thus, the case study design is considered an ideal vehicle for exposing students to energy and sustainability issues; students are expected to be especially motivated by projects focused on these areas since they currently represent one of the greatest professional challenges and a source of career opportunities for future graduates. During the implementation of the project, students must decide on several aspects of the design, such as the raw material to be used, the final flowsheet and the process equipment, and the operational conditions; they must also make a preliminary economic estimation to assess the commercial viability of the process.

Students are expected to approach the project with a solid knowledge base in basic chemistry, industrial process subjects and chemical engineering subjects, studied during the previous two courses in the chemical engineering degree. The project allows students to present the previously learned methods and knowledge necessary for the conceptual design of a chemical plant that operates continuously. Special attention is given to understanding modern design approaches that are used in industry and to dealing with problems of current interest.

A session is dedicated to introduce students to the main challenges of using conventional fuels for energy; the need to discover an alternative energy source using renewable raw materials, where bioethanol would be an attractive alternative option, is argued. Students are given an overview of the production of ethanol as a fuel from lignocellulosic biomass, together with the main bibliographic references in the form of review papers.

PBL is particularly useful in small groups of 3 or 4 students, although its effectiveness depends on the amount of effort that each student is willing to make in resolving problems and in analysing and interpreting data whilst studying (English and Kitsantas, 2013). How to arrange students into suitable groups is given ample consideration in the literature (Blowers, 2003). In order to obtain balanced groups, three basic skills were defined, and in each group, one or more of its members must have one of those skills. These basic skills are: (i) good communication skills; these include not only oral communications skills, but also information management, technical report writing and the ability to use computer programs; (ii) strong math skills, to perform calculations, verify solutions and units, and the ability to use spreadsheets; and (iii) basic knowledge of chemical engineering, which the student is expected to have acquired from successfully studying all the subjects of the industrial chemistry module of the course.

Work groups are required to prepare three different project reports (named Memories) and an oral presentation that will be useful for showing the main findings during the course and for evaluating part of the learning process. Each report must include: a covering letter; a description of the tasks they have carried out; the methodology applied; and the main results obtained. A Bibliography sections and an Appendix must also be included in the report. The final oral presentation of the whole project, made using Power Point, must include presentation of the teamwork, key indicators of the design, and major remarks and recommendations.

The purpose of the Memory 1 report is to inform how the group selected the alternative process to be adopted to produce second-generation bioethanol, and to present the process flowsheet drawn by the group. To do this, students must perform a literature review of the alternatives for producing bioethanol from lignocellulosic biomass via hydrolysis, and represent these alternatives in a superstructure diagram. The alternatives considered should be briefly discussed, and from among these, one must be selected. A flowsheet with an appropriate level of detail must be presented, with all the items of equipment required shown and labelled. The text should lead the reader through the flowsheet, briefly describing the function of each main unit included in the major process streams. A complete equipment list must be provided in the appendix. The main conclusion of the Memory 1 report should be a gross costing and expected profit calculation for this process, including the storage and transportation costs, making reasonable assumptions, to determine if it is worth proceeding.

In the Memory 2 report, the group must present the process design, i.e. the heat and material balance performed to determine the temperature, pressure, composition, total flowrate, and phase condition for every stream on the flowsheet. From the literature review, the group must obtain all the specifications for the unit operations or/and equipment of the selected process, and produce a quantitative flowsheet. The work done to derive the mass and heat balance models, as well as the assumptions behind the calculations, need to be described. Each calculation should be illustrated with an example from the selected flowsheet including the algebraic formula, the numerical values and the result.

For Memory 3, the group have to size the equipment of the flowsheet reported in Memory 2, perform heat integration, and present an economic evaluation. Based on the mass and energy balances, a complete calculation for the sizing and costing of every major piece of equipment must be included. For minor or frequently-occurring similar equipment such as heat exchangers and gas compressors, a single representative calculation is sufficient. An equipment list with the results of sizing and estimated cost of each individual item of equipment must be presented. Total equipment costs, capital cost estimation, manufacturing cost, and utility costs must be calculated and presented using pie charts. For the economic evaluation both discounted and non-discounted financial criteria must be applied, together with a sensitivity analysis of key parameters. Finally, the group must offer a recommendation on the economic viability of the process. The relevance of all this information is extensively explained to students in the guidelines for each Memory report.

The project-based-learning approach and the strategies for assessing students' learning have been applied on the Chemical Process Design course, a compulsory course accounting for 6 ECTS that is part of the Chemical Engineering degree (total 240 ECTS). In a previous article (Galan et al., 2016) the authors described the innovative practices implemented in this Design course that are relevant to this kind of study, in which students learn to manage complex tasks of an open-ended and unstructured nature, with a high degree of abstraction. This course is delivered in the first semester of the third year in the School of Industrial Engineering and Telecommunications, a Polytechnic School at the University of Cantabria, Spain.

Process Design requires the creative solution of open problems, the justification of proposed solutions by technical analysis, and the translation of these results into technical language in specifications, mathematical models and engineering drawings (Seider et al., 2009). As one of the key subjects in chemical engineering education, Process Design provides the vehicle for the integration of previously-learned engineering fundamentals and management skills acquired, important for real-world engineering practice, by applying active learning methods and diverse assessment approaches (Biegler et al., 2010). To complete the course background with relevant demographic information, the course cohort of the 2017-2018 academic year was a class of 45 students (29 female and 16 male), and in the 2018-2019 academic year, a class of 30 students (18 female and 12 male), all of them full time students. Their typical age was 21–22 years old.

2.2 Course objectives, learning activities and assessment tasks

Figure 1 shows the course-specific learning objectives, including the course outcomes that the students will attain after the four consecutive learning stages of Synthesis, Analysis, Evaluation and Project Presentation. In Table 1 the desired outcomes and the learning activities, including the formative assessment, are aligned with the assessment activities proposed to meet these objectives. Learning and assessment methods used in the course should help students to achieve learning objectives and problem-solving, among other transferable skills, by encouraging students to study actively and continuously in a cycle of four learning stages.

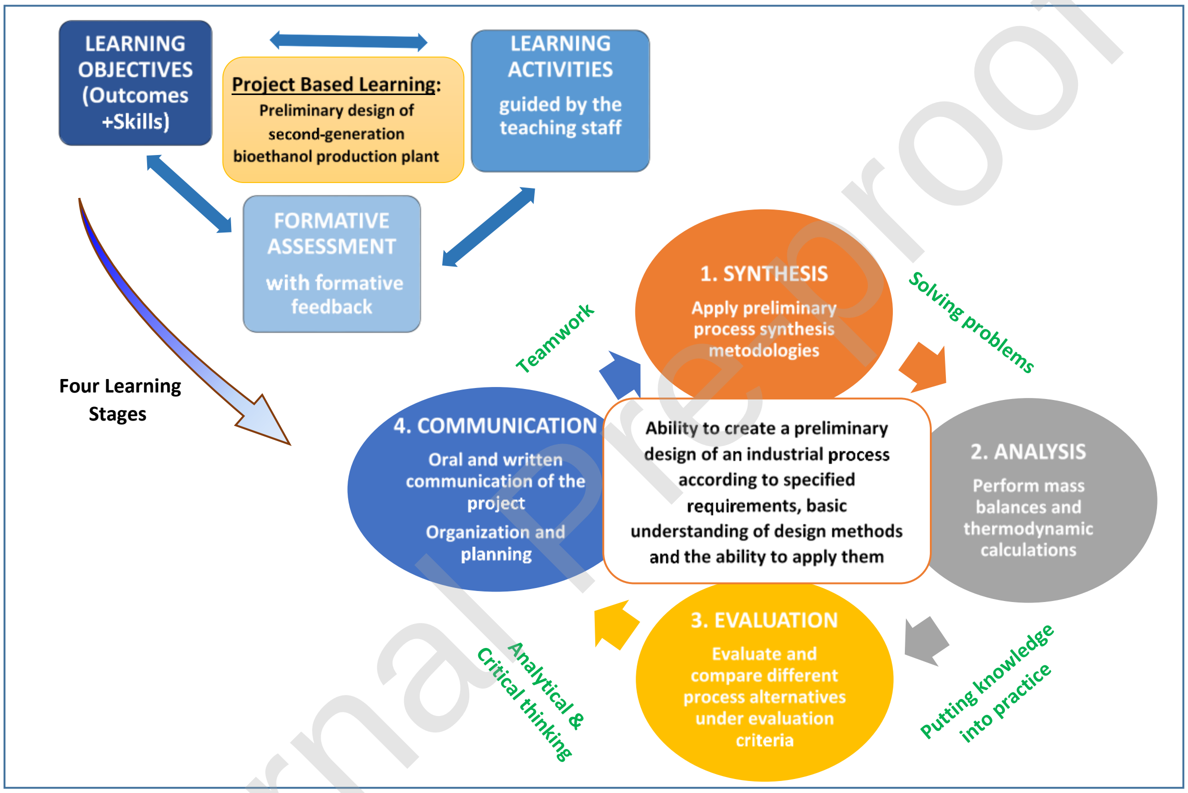

Figure 1: Learning objectives outcomes and skills of the four consecutive learning stages of the project.

The course is organized under a PBL approach with 60 h of class time (15 h lectures and 45 h mentor sessions), 25 h of tutorials & assessment and 65 h of study (individual and in teams) time. Each class met for 50 minutes, four times a week, for 15 weeks. All learning activities are designed and applied under an instructional strategy oriented to reinforce the learning objectives and to prepare students for assessments. Lectures are prepared under a flipped classroom approach, with slides and videos hosted in Moodle serving as a suitable complement for the PBL strategy (Moreno-Ruiz et al., 2019). The lecture class begins by resolving the students' doubts about the videos and then working in class with brief examples and case studies related to the group project.

Table 1. Aligned learning objectives, learning activities and assessment activities in each project stage.

Project step	***Specific Learning Outcomes/skills***	***Specific Learning Activities***	***Specific Assessment Activities***
Synthesis	• Apply hierarchical decomposition methodology, obtaining flowsheets by successive refinement. • Create, interpret, use and describe Superstructures • Teamwork • Decision making • Screening alternatives • Analytical and critical thinking • Putting knowledge into practice	• Active watching of video lectures on process synthesis + Solving doubts about video contents • Examples of superstructures: heat exchange network, wastewater treatment network, ammonia plant. • Brief questions about lectures hosted in Moodle • Exercises of synthesis of alternatives by hierarchical decomposition • Bibliographic search of bioethanol production alternatives (raw materials and processes) • Elaboration of a superstructure of alternatives. • Writing a technical report	• Formative Assessment of Memory 1 using a Rubric (Fig. 3a) to evaluate the scope, originality, creativity, accuracy and whether the Superstructure of alternatives is reasonable, neatly and clearly drawn. • 2 Kahoot (total of 20 questions) • One-third-term exam
Analysis	• Perform mass balances and thermodynamic calculations • Make educated guesses • Analytical and critical thinking • Solving problems • Teamwork • Dealing with simplified analysis models • Putting knowledge into practice	• Active watching of video lectures on mass & energy balances + Solving doubts about video contents • Examples of short-cut calculation for major unit operations: mixer, splitter, reactor, flash, distillation and absorption • Brief questions about lectures hosted in Moodle • Exercises of mass and energy balances • Writing a technical report	• Formative Assessment of Memory 2 using a Rubric (Fig. 3b) to evaluate the quantitative process flow diagram, its calculations, assumptions and description • 2 Kahoot (total of 24 questions) • One-third-term exam
Evaluation	• Evaluate and compare different process alternatives under evaluation criteria • Teamwork • Decision making • Screen alternatives • Analytical and critical thinking • Putting knowledge into practice	• Active watching of video lectures on equipment sizing and costing + Solving doubts about video contents • Simplified analysis models for sizing and costing of vessels, heat transfer equipment, compressors, pumps, refrigeration, distillation and absorption • Application of economic criteria to brief examples • Brief questions about lectures hosted in Moodle • Write a technical report	• Formative Assessment of Memory 3 using a Rubric (Fig. 3c) to evaluate the sizing calculations and the items and quality of the financial discussion on costings & returns • 2 Kahoot (total of 24questions) • One-third-term exam
Communication	• Oral and written communication of the project • Technical communication • Organization and planning • Teamwork	• Making a convincing technical presentation • Oral presentation of the process developed	• Peer- and self-assessment using a Rubric (Fig. 3d) to evaluate the quality of presentation and discussion • Co-evaluation (Fig. 3e) • Teacher evaluation

Every lecture includes a section highlighting the issues that are important to learn. Formative assessment and one-third-term exams under a philosophy of assessing to learn incorporating feedback, allow continuous monitoring and reinforcement of those concepts that are found to be most problematic. Previous years' exam questions are considered in class; and after each term exam, the most appropriate answers with general feedback are given by the teacher to the students. During mentor sessions and tutorials, the course teacher circulates around the groups and spends 15–20 min/week with each group to discuss their progress and the direction of their work, and give mentoring support for technical aspects, time management, and modes of interaction within the work group. During these face-to-face group classes teachers answer any queries, open dialogue with students to interpret rubrics and understand how they are manifested in the project report, with the object of stimulating students' capacity for critical analysis and personal reflection, and encouraging the group members to get involved in the project. The forums in Moodle and e-mail foster interaction among the students, and communication and continuous advice between the students and the teaching staff.

The assessment process is a systematic way of measuring students' learning. It is important to choose a methodology that effectively assesses the fulfilment of the objectives of the course. Several different assessment techniques have been applied – specifically, formative assessment, self-, peer- and co-evaluation applied to the teamwork, and individual exams and active participation in individual and small group exercises, and clickers like Kahoots. Each assessment approach given in Table1 is mapped to a particular outcome. Formative Assessment assesses specific outcomes of each project step developed under a teamwork, according to the evaluation rubrics of each step. The cognitive and knowledge acquisition of learning outcomes is assessed by the exams. Peer-, self-assessment and co-evaluation assess the whole project during the Communication step, according to the evaluation rubrics specific to evaluate the global project showed during the oral presentation.

Figure 2 shows the scheduling of the activities involved during the assessment process applied as an integral part of the higher education course encompassing different periods within the total 15 weeks.

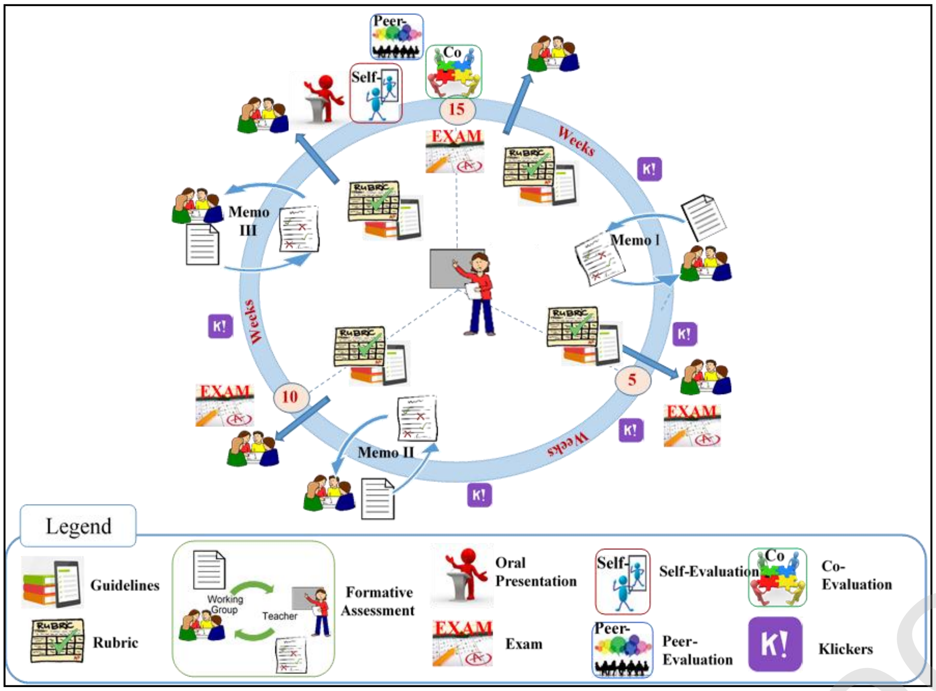

Figure 2. Scheduling of the assessment process

2.3. Formative Assessment

As part of the assessment strategy, several formative assessment techniques providing formative feedback on student learning have been included in the instruction; these are designed to improve teaching effectiveness. The feedback ranges from simply stating whether an answer is correct (used in the Kahoot clickers), to giving elaborate, content-related, qualitative feedback based on the rubric or feedback form employed in the written Memories.

In each mentor session, the teams explain the progress made that week in the project to the teacher and obtain a continuous feedback. Once the project report is elaborated, in specific sessions, a representative of each group reads the covering letter to the class, and the classmates can give their opinion about it. Afterwards, the teacher corrects the reports, which are later returned to the working groups with written comments, and provides feedback about positive features and how to improve the report and correct any mistakes. The teacher presents common and critical questions to the rest of the groups. The feedback process applied implies that in the next project report the student should demonstrate some of the learning outcomes judged in the previous project report.

The evaluation of each project Memory and oral presentation is made according to evaluation rubrics.

The rubrics are created to describe explicitly the instructor's expectations regarding group performance on the various different aspects of successfully designing the particular chemical process assigned to the student working group, and are very helpful in guiding students in their learning process. The rubrics identify the criteria or aspects of performance that will be assessed aligned to the course outcomes (items) (e.g. generating a superstructure of alternatives, applying short-cut design calculations to solve mass balances), the characteristics associated with each dimension or descriptor (e.g. reasoning used for screening the process alternatives; whether the Process Flow Diagram is reasonable and accurate; analysis of the main items in the financial feasibility study) and four performance levels that record each student's level of mastery with respect to each criterion, from A (Excellent) to F (Fail). Students were given the rubric with the assignment guidelines for the project (Figure 3a,b,c).

Self- and peer-assessment is applied to assess the whole project at the oral presentations; this is one of the most commonly applied approaches for assessing teamwork (Chen, 2010); it also provides an opportunity for the student to develop expertise in evaluating project teamwork. Students are given the opportunity to evaluate qualitative and quantitative aspects of the global projects of all groups, including their own group, using the evaluation rubric of shown in Figure 3d. The method applied for co-evaluation in teamwork is a modified version of the method first proposed by Croft et al. (1995) and used by Planas-Lladó et al. (2018), whereby each student has to carry out a self-assessment and also assess the other members of the student's team. For example, if a team of three is awarded a mark out of 8, the maximum number of accumulated points would be 24; taking into account the criteria established in the rubric, the members of the group distribute the points by negotiation amongst themselves (Figure 3e). The negotiated co-evaluation is expressed directly in marks (Table 2). Furthermore, various quizzes are applied at the end of the lesson modules, using Kahoot. According to Kay and LeSage (2009), clickers can improve learning processes, giving the students opportunities to reflect on what they have learned, to control their own understanding and to monitor their own learning process. In addition, the teacher can check whether the students have understood enough before moving onto a new topic.

Table 2. Summary of unit assessment items

Assessment item	***Marks weighting***	***Description***
Final design report (whole project)	**42**	**Final Group mark from negotiated co-evaluation**
Design report (Project Memory 1)	13	Preliminary Group mark
Design report (Project Memory 2)	14	Preliminary Group mark
Design report (Project Memory 3)	15	Preliminary Group mark
Oral presentation of the whole Project	**13**	**Group mark + self- and peer-assessment**
Total Exam (Mid-term or Final)	**40**	**Sum of the individual marks**
One-third-term exam 1	13	Individual mark
One-third-term exam 2	13	Individual mark
One-third-term exam 3	14	Individual mark
Individual/small group exercises and clickers	**5**	**Individual mark**
TOTAL	**100**	

There are three one-third-term exams where students are asked about concepts of both the theory and the project they are undertaking. They have to obtain a mark of more than 4 to pass, but if they fail any exam, they have another opportunity in the final exam at the end of the course. The student marks obtained in each assessment technique applied, together the statistical analysis of the results of the students´ perceptions using the co-evaluation rubric, are analysed by the SPSS v.22 software.

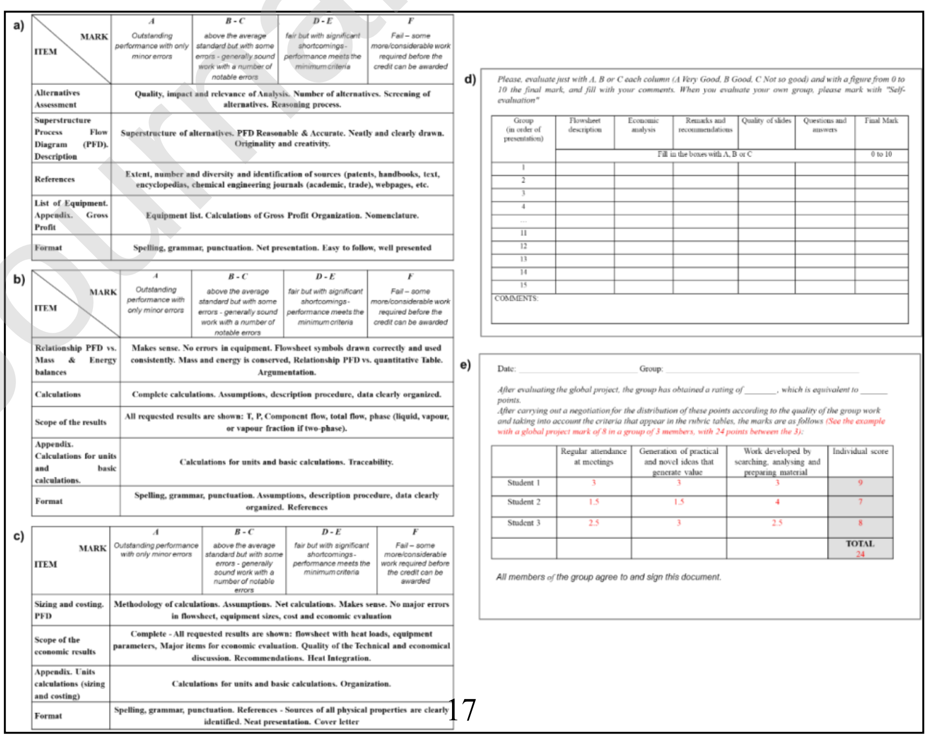

Figure 3. Evaluation rubrics for written reports: a) Memory 1; b) Memory 2; c) Memory 3; d) Oral presentations; and e) Co-evaluation rubric, for each work group, with example of application

2.4 Evaluation of the assessment strategy

The review of Struyven et al. (2005) shows that students´ perceptions about assessment significantly influence their approach to learning and studying. These perceptions serve the valuable purpose of guiding teachers in their reflective attempts to improve educational practices and achieve a higher quality of learning and education for the students.

In this work, students were requested to complete an anonymous and voluntary survey to evaluate specifically the different assessment methods applied during the course, as well as the grading/marking system. The survey was developed by the authors by combining the validated questionnaire of Castejón et al. (2015), from the Spanish Training and Shared Evaluation Network in Higher Education, with other questionnaires proposed in the literature (Palmer and Hall, 2011; Salmisto and Nokelainen, 2015). Participants were asked to score the extent to which they disagreed or agreed with statements using a Likert scale from 1 (completely disagree) to 4 (completely agree). Each section of the questionnaire also requested comments and/or proposals. The survey consisted of seven sections with 31 questions (Table S1-Supplementary Material) regarding different aspects of the course assessment and mark allocation systems, such as: the participation of students in the assessment and grading process of the subject (4 items), the formative assessment and evaluation rubrics (7 items), the co-evaluation rubric (4 items), the peer-evaluation and self-evaluation (4 items), the grading of the whole subject (2 items) the grading of the project (3 items), and finally regarding the global aspects of the subject (Chemical Process Design) (7 items). The timing of the survey coincided with week 16-17 of the semester after the final grades. To analyse the closed questions in the questionnaire, the SPSS v.22 software was used and a descriptive statistical procedure was undertaken.

3. Results

3.1 Applying the formative assessment to teamwork

The formative evaluation was carried out once students had delivered the reports and the teachers had returned the corrected reports to the working group, with notes for improvement and the mark awarded, from A to F, defined in the rubrics. In each year, a total of 45 and 30 students respectively were subject to continuous evaluation by means of the proposed methodology; they studied and learned in 15 and 10 work groups in the 2017-18 and 2018-19 academic year respectively. The formative assessment allowed the provision of regular, timely, detailed and constructive feedback. The trends in the project report grades obtained by each group are shown in Table 3.

Having created, by means of the formative assessment applied, conditions of positive reinforcement for the students to proceed to the next stage in learning, eleven of the working groups (44%) increased their marks gradually with time. In contrast, two groups (8%) presented marks that gradually decreased over time. Five groups (20%) presented consistent marks across the successive three Memories; and seven groups (28%) presented marks that alternate between positive and negative.

Table 3. Grades obtained by the groups for the Memories in the formative assessment of Teamwork (Each row shows the grades of one Work Group)

Grades Trends	Memory I	Memory II	Memory III
Very positive trend	E	C	B
	D	*C*	*B*
	C	*B*	*A*
Positive trend	*B*	*A*	*A*
	C	C	B
	D	C	C
	D	C	C
	D	*C*	*C*
	E	*C*	*C*
	E	C	C
	F	*C*	*C*

Grades Trends	Memory I	Memory II	Memory III
Equal	*A*	*A*	*A*
	B	B	B
	C	C	C
	C	C	C
	D	D	D
	B	*C*	*B*
Negative & Positive	C	D	C
Positive & Negative	*F*	*B*	*D*
	E	*B*	*D*
	D	B	C
	C	B	C

Course 2018-2019 grades in Italics	***C***	***B***	***C***
Negative trend	**B**	**C**	**C**
	C	**C**	**D**

3.2. Correlation between peer- and self-evaluation and teachers' marks

In the present work, the oral presentation was graded by the teachers, and a student self- and peer-evaluation of each working group was applied. Figure 4, in "box and whiskers" format, allows comparison between the peer-, self-, and teachers' assessment marks of the 25 working groups during 2017-2018 (15 groups) and 2018-2019 (10 groups) academic years.

In Figure 4, peer-evaluation shows marks awarded out of 10 with high dispersion between minimum and maximum, ranging from 1.5 to 4 discrete marks/grades; the quartiles vary from 0.5 to 2 grades. Weak positive correlations with very similar slope have been obtained between self-assessed marks and the teacher's marks (R^2=0.33), and between the average value of peer-assessed marks and the teacher's marks (R^2=0.49) (Figure S1- Supplementary Material). According to these correlations, the self-assessment mark is an average value of 0.6 points higher than the peer-assessment mark. With respect to the estimation of mean marks out of the possible 10, peer-scoring (7.7±0.70) was the strictest and self-scoring (8.3±0.71) the least strict marking.

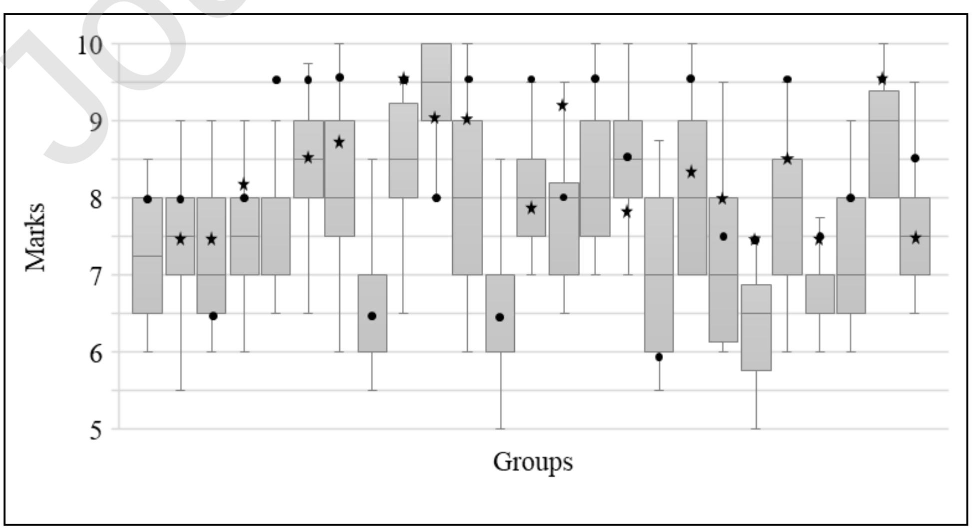

Figure 4. Self-, peer- and teachers' assessment marks of the oral presentation of the global project report. The "whiskers" span the maximum and minimum values and the central "box" spans the first quartile to the third quartile of the peer-assessed mark: (★) represents the self-assessed mark and (●) the teacher's mark.

3.3 The use of the co-evaluation as a technique for distributing group marks for teamwork to individual group members

Once all the activities associated with the project were completed, a global mark was given to each group. The co-evaluation technique applied in the present work consists of the distribution of the teamwork activity marks (for the three Memory reports and oral presentation) decided by consensus among the team members. Using a rubric (Figure 3e), team members had to evaluate the work of each member of their own team according to three different criteria. Two conclusions are obtained from the co-evaluation process: (i) eleven working groups (44%) did not share the group mark equally between the team members; they considered it more equitable to allocate marks that differentiated between individuals by between 0.2 and 2.1 points; and (ii) with respect to the criteria applied in the rubric, the item "Work done in searching, analysing and preparing material" shows statistically significant differences (p=0.015 under the non-parametric Mann-Whitney test) compared with the other items (Fig. S2-Supplementary Material). The students perceive this criterion, as opposed to the other two criteria, "Generation of ideas" and "Regular attendance", as the most sensitive in relation to the individual's involvement in the work done during the process of cooperative learning.

3.4 Traditional exams as an assessment technique

One-time written exams tend to encourage students to make an intense one-time effort to learn. In the present study, three one-third-term exams are applied, plus a final exam (only for students who failed one or more of the one-third-term exams). Each exam consists of four short questions where a justification of the answer is required, 2 multiple-choice concept questions, and 2 quantitative problems. The students took the exams after the formative evaluation of each project report, allowing the students to incorporate the teacher's feedback to their learning and the connection between the two assessment techniques. Nine students (12%) did not attend the exam evaluation despite having passed the project evaluation part; this is due to some students taking subjects from previous courses that leaded them in high teaching load, and students with poor performance in the one-third-term exams that displayed a lack of engagement with the final exam. Seven students (9%) did not pass the exam. The overall marks of the students passing the exam (59 students), after the application of all the evaluation methods, present an average of 7.2, from the lowest mark of 5.1 to the highest of 9.5. We evaluate the differences apparent from the different assessment methods by correlating the exam marks with the project marks for each student. The poor fitted correlation obtained (Project Mark = 5.8 + 0.5 [Exam Mark], R^2=0.30) shows there are wide differences in assessment (Figure 5), suggesting that the two types of assessment measure different learning outcomes and competences (Hoffman et al., 2006). The overall grades for the course did not provide feedback to identify which skills the students found more difficult to acquire. However, the different scores among assessment methods (Exam marks and those related to Project work), allow a class-level analysis of strengths and weaknesses. The class overall showed weakness in the specific learning outcomes assessed by the exams in relation to knowledge acquisition, but showed strengths in other skills such as team-work, analytical & critical thinking, technical communication and decision-making skills, assessed by formative and continuous assessment.

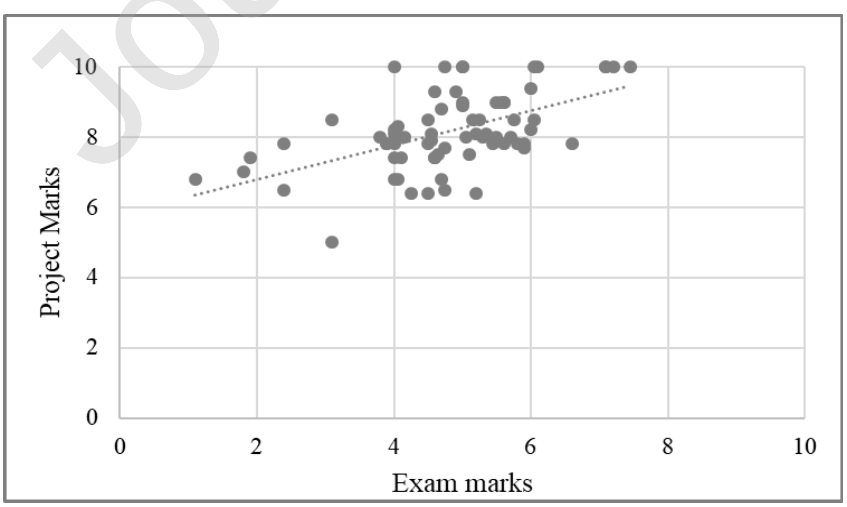

Figure 5. Comparison between global project marks and exam marks

3.5 Students' perceptions of the proposed integrated assessment techniques and proposals for improvement of the designed approach to assessment

Students' views offer a way forward for improving educational practice (Struyven et al., 2005). The evaluation of student perceptions through questionnaires has been proven useful for the evaluation of active learning techniques in engineering education (Palmer and Hall, 2011). The aim of the survey carried out as part of this study (Table S1-Supplementary Material) is not only to gauge student opinion but also to identify possible risks in planning the assessment strategy. The survey is focused on how students perceived the assessment methodology applied and on how it affected their learning efficiency, with the object of identifying the benefits and difficulties of the implementation of innovative concepts regarding evaluation.

The survey was conducted at the end of the courses 2017-2018 and 2018-2019, once the students had done the final exam of the subject and knew their final mark, in order to obtain feedback on their experiences as complete as possible. A total of 56 students responded to the survey; this represents 75% of the cohort. A detailed analysis of the results obtained from the 31 items of the student satisfaction/opinion questionnaire has been carried out using the statistical program SPSS v.22. Statistical descriptive parameters (quartiles, average) and the relationships of significance between the items of the questionnaire are analysed in terms of variables such as the year when they completed the subject, age and gender. For this, the Kolmogorov-Smirnov test was performed first, relative to the normality of the sample, and it was found that in all cases ($p < 0.05$) the sample follows a non-normal distribution for performing nonparametric analyses (Mann-Whitney and the Kolmogorov-Smirnov test for two samples). The non-parametric tests reveal that the outcomes of the survey depending on the year analysed, the gender of students and the age, show no significant differences ($p > 0.05$) so that the analysis of the results can be performed as a single sample. The results are summarized in Figure 6 in a “box and whisker” diagram.

These results can be summarized as follows according to each analysed section (B to H) of the survey and considering the percentage of responses with values of 3 and 4 over all responses (1 to 4) for each question.

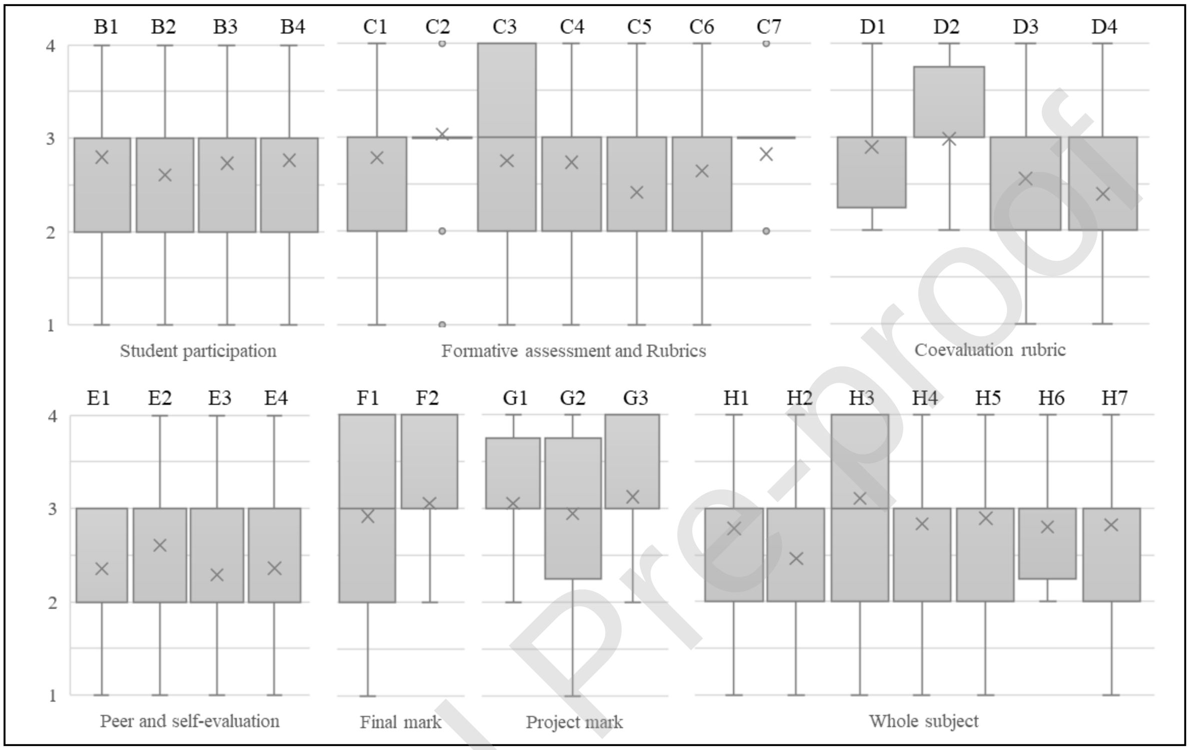

Figure 6. Results of the evaluation of students’ perception of the assessment strategy according to the questionnaire devised (see Supplementary material). The “whiskers” represent the maximum and minimum values; the central “box” spans the first quartile to the third quartile, the (X) represents the arithmetic average and (●) represents outliers (observations that fall an abnormal distance from other values in the sample from a population). Sections B to H are the sections in the questionnaire in which answers to the individual questions are represented by a number.

The average value in the section B “Student participation” is 2.8. This indicates that the students have a positive opinion of the different evaluation methods applied in the subject. There is broad agreement (71%) that the combination of evaluation methods is an effective way to improve their learning (B1), and to stimulate their interest (60%) (B2). Furthermore, they agree that the final mark is fairer (68%) (B3) and has a positive influence on the development of the transversal skills (71%) (B4), mainly teamwork, decision-making, project design and management.

In relation to the "Formative assessment and rubrics" (section C), the most positive results are that this method gives importance to daily work (82%) (C2), the method generates significant learning (77%) (C7) and it was clear to the students what assessment work was expected (C1). There is a wide variety of opinion regarding whether the teachers' comments help to improve their work (C3) even though 61% of students agree with this statement. In contrast, only 48% think that this methodology allows more individual follow-up (C5).

There is agreement that taking into account the opinion of their teammates by the "Co-Evaluation" (section D), improves the result of their work (79%) (D2); but co-evaluation is not considered to result in improvement of the work environment (D3), and only 45% consider that the learning process was improved (D4).

Students are more critical about "Peer- and self-evaluation", surveyed in section (E). Only 43% of students agree that peer-evaluation improves the learning process (E1) and this same proportion did not feel competent enough to assess their peers. However, 64% of them agree with self-evaluation (E2); none of them totally agrees with these statements. Furthermore, 40% think that these techniques should be applied to the written reports (E3), and 60% agree that they should continue to be applied to the oral presentation.

In section F "Grading of the subject", 75% of students are satisfied with the final grade obtained (F1) and 80% agreed with the weight assigned to each part of the subject (exam and project) (F2). It is highlighted that some students proposed a higher weight of marks to the project in comparison with the exam (proposed 70/30 vs current 60/40 weighting). The opinion of students about "Grading of the project" in section (G) is very positive, with an average value near 3. They understood the grading system (G1); more than 75% think that the grade assigned by the teachers is justified (G2); and the weight of each of the three reports and the oral presentation is correct.

Regarding the "Whole subject" in section H, most of the responses have an average value between 2.5 and 3. The majority of students (68%) think that this course applies a methodology (Project based learning) that is different from that to which they have previously been accustomed (H1), and 73%

respond that it requires more effort than the traditional methodology (H3). The majority of students (67%) believe that the level of difficulty of the subject is high (H5), but most students state a high level of overall satisfaction with the evaluation process (H6) and with the subject (H7), at 75% and 71% respectively.

In their survey responses, the most frequent comments of the participants were about lack of accuracy of the peer evaluation and the discrepancies that emerged in the co-evaluation; one student stated: "(resolving) this conflict helps to develop other transversal skills such as assertiveness and objectivity". The use of clickers is a very well-received aspect by the students in their comments.

4. Discussion and Conclusion

4.1. Discussion

Chemical process design, with a conceptual design approach, is a chemical engineering course of special interest for the application of different active-learning methods and a variety of assessment approaches such as formative assessment, self-, peer- and co-evaluation, exams and individual/small group exercises, and clickers. All of these incorporate corrective feedbacks given by the teacher in a continuous way, in order to enhance the students' learning, as stated in the review work of Cimer (2007). These different grading techniques have been brought sequentially into the subject in order to analyse the students´ perceptions and the learning improvements in an academic environment with scarce previous use of the proposed techniques.

The three reports (Memories) to which formative assessment has been applied under a PBL approach are sequential, incorporating new tasks that cover different topics such as synthesis, analysis and evaluation of processes respectively. However, we would expect an improvement in the marks, given that some of the tasks are common throughout the three Memories of process design. The learning aspects that are common to the three Memories include the decision-making process, learning to deal with simplified analysis models, learning to make educated guesses and learning how to screen alternatives; in addition, as shown in the rubrics, continuous improvements over the course of the three Memories are possible in tasks such as the process flow diagram, the material and energy balances, as well as issues of formatting, evaluated with the same standard of marking. Furthermore, the design process includes returning to the previous stage to improve the tasks completed (calculations, assumptions or design progress decisions). The negative trends observed in Table 3 may be due to the high workload accumulated at the end of the semester and the discontinuity in work due to the Christmas holidays, detected during the weekly monitoring of the students' participation in the group task; time management issues have been identified previously as difficulties experienced during studies (Wallin et al., 2019). Although these trends account for less than 30% of the groups studied, special attention must be given to them in the scheduling of activities for subsequent courses.

Various studies have been conducted in which peer- and self-evaluation are applied in the assessment of oral presentations in various subjects of different degrees courses including engineering subjects. These studies present both similarities and differences in their results and analysis, and a wide range of correlations between marks awarded by teachers and the students (in both peer- and self-assessment) (Suñol et al., 2016). In general, the agreement between self-, peer-assessed grades and the teacher-awarded grades varies widely depending on pedagogical strategies applied, students' previous experience, age groups, assessment tasks, subjects and time periods; in addition, worse correlations can be expected in assessment of mainly qualitative subjects such as the oral presentations made by students without previous experience with self-evaluation, as in the present work. High reliability of correlation between students' self-grading and teacher grading have been obtained previously (Boud, 1995; López-Pastor et al., 2012), although weak-to-moderate correlations between self-, peer- and teacher-grading have also been reported in the literature (Sadler and Good, 2006; Chen, 2010).

The peer- and self-evaluation results obtained (Figure 4) are in accordance with the findings of Sadler and Good (2006) who show that peer-grading tends to undergrade while self-grading tends to overgrade. Students were given a five-category rubric for assessing oral presentation skills (Figure 3d) together the specific guidelines for oral presentation aligned to the course-specific learning objectives (transversal skills). However, the observed disparity between peer- and self-gradings (an average value of 0.6 points out of ten) may be reduced by creating specific criteria for each category. On this point, it is important to define and explain clearly the assessment criteria to avoid these disparities, especially when the project tasks are extensive and the teams are large in number (Raban and Litchfield, 2007). In any case, self- and peer-assessment are both valuable processes in the student learning process. In addition, Falchikov and Goldfinch (2000) suggest avoiding the use of proportions of agreement between peer-, self- and teacher marking as a measure of the validity of the methods, because these methods, with the provision of feedback, may also be used in the absence of marking, with many formative benefits in terms of improving student learning. Similarly, McGarr and Clifford (2013) highlight the collaborative learning task rather than the assessment calibration exercise of peer-assessment. Both peer- and self-assessment have a positive effect on students´ learning, helping them to gain analytical and critical thinking skills, as well as the ability to evaluate technical presentations in the first cycle of the chemical engineering degree. The improvement in learning can have a special impact in creative subjects, like Chemical Process Design, where a high degree of abstraction, the generation and study of multiple alternatives, and the diversity of criteria to be applied, are key characteristics. The review by Day et al., 2018 shows that the category of feedback (simply or elaborated) does not produce different positive effects, and that peer assessment is beneficial to students' grades, especially since providing feedback is a learning opportunity for students as well.

In relation to the use of co-evaluation in teamwork as a method for distributing individual marks in teamwork, the provision of a clear criterion rubric, under a co-evaluation procedure based on agreement, has been adopted as a strategy for obtaining good judgement and honest marking (Sridharan et al., 2019). The co-evaluation process allows the creation of a metric for analysing the perception that their team-mates have of the involvement and contribution of a student to the working group, which is reflected directly in the final individual mark awarded by the teachers. Therefore giving students responsibilities for grading by co-evaluation serves as mechanism that gives more visibility to the individual contribution. In general, in the assessment of team work applied to the Chemical Process Design subject adopted in previous works one or more assessment approach such as those described in the present work were used (Langrish and See, 2008; Davey and Palmer, 2012; Fletcher and Boon, 2013, Wankat and Bullard, 2016). Other methods as the use of monitoring questions to measure the level of knowledge acquired by individual team work members (Aranzabal et al., 2019), anonymous peer feedback (Sridharan et al., 2019) or co-evaluation by confidential procedures (Ko, 2014) have been used too. Not all of the assessment examples had positive outcomes and in some cases the academic staff found it difficult to develop or apply assessment criteria to evaluate student learning in team group; in many cases students´ perceptions of the different assessment tactics remained diverse (Kaufman et al., 2000; Simper, 2020).

In relation to the student's perceptions of the proposed integrated assessment methodology, the validity of the data obtained through the questionnaire can be affected by how the students interpret the questions as well as their experience of assessment. The answers are based on students' perceptions, in a particular Chemical Engineering program of one Spanish educational context and are limited by the moderate sample size and the two-year duration of the study taking place within a specific teaching domain.

These results are aligned with those obtained by Pereira et al., 2017 in two different national education systems. A creative discipline like the conceptual Chemical Process Design that entails decision-making with limited information on open-ended problems, can represent a source of anxiety for the student on the one hand but a stimulus for engagement on the other (Carless, 2015).

The exam marks (average 5.1±1.2, out of 10) obtained by the students are lower than the project marks (average 8.2±1.1, out of 10). One factor in weak exam grades highlighted by Parsons (2008) could be examination stress. Although 80% of the students (F2 in Figure 6) agreed with the evaluation weighting assigned to each part of the subject (exam 40% and project 60%), the higher weighting of marks to the project with respect to the exam could be a subject for analysis. Another aspect to take into account is the effect of increased feedback on the examination performance; feedback can improve test-taking since it allows students to assess the amount of work they need to do for their exams (Knight, 2001). Authors agree with previous studies that individual examinations are a common way that can be effective to boost individual accountability (Laal et al., 2013; Aranzabal et al., 2019). Authors would maintain this assessment approach with a minor weighting in the overall mark. In order to reduce absenteeism and improve exam performance authors propose that students feel more confident in taking the exam, reducing examination nervousness, anxiety, and stress offering seminars (1h/week total 15 weeks) dedicated to monitoring and reinforcement of those concepts that are found to be most problematic.

The students` perceptions show a generally positive integration of the assessment tasks (Section B), the feedback actions (section C) and the students´ development of expertise in evaluating teamwork (Sections D and E). These core elements of learning-oriented assessment proposed by Carless (2015) are well-illustrated in a creative discipline such as the conceptual Chemical Process Design course studied. Positive perceptions of students about the adoption of a continuous assessment approach have been reported previously by several authors, such as Kniveton, 1996; Tuunila and Pulkkinen, 2015; students consider it a better way to judge their skills and a good tool for working time management.

4.2. Conclusion

In the working group project described, formative assessment under rubrics specifically created, has enabled regular, timely, detailed and constructive feedback of the teamwork activities to be provided to both students and teachers. According to the opinions expressed by the students, this approach to assessment generates significant learning, and will continue to be a subject of special attention given the importance of effective teamwork, which is one of the skills most valued by employers. It is, however, essential to improve the rubrics for assessing learning activities that have high qualitative content and are more susceptible to students' subjective capabilities, such as oral presentations, designing specific criteria for the mechanics of communication, scheduling activities, and the quality of presentation and question-answer sessions. Students have a positive perception of the evaluation strategy after two academic years; they value their experience as an effective way to learn; it has a positive influence on the achievement of transversal competences; and they are satisfied with the final mark. The co-evaluation process has been an effective tool for considering the differing contributions made by working group members, which is reflected successfully in the final individual mark awarded by the teachers. However, students' opinions about the peer-evaluation are less positive: some students conclude that it is not an objective mechanism, since it is influenced by their personal relationship with their classmates. Active student participation in the design and application of the rubrics is proposed with the object of incorporating peer-assessment in the written reports, with students giving feedback; this approach could enhance future learning performance and should make the peer-assessment fairer and more objective. In this sense, a complementary strategy could be applied in the future to determine the individual mark of the workgroup, based, for example, on the results of monitoring questionnaires.

The experience gained by students, the improvement of their learning strategies and their enhanced motivation may be an incentive for other teachers to try to generate similar dynamics; however, it is necessary to overcome potential obstacles such as the need for organizational changes and better teacher-training whereby innovation is encouraged. The learning-oriented assessment approach proposed could also contribute to formative and summative assessment in various subjects of the chemical engineering degree, particularly in the more creative topics such as Process Simulation, Product Design and others, as well as in other degrees within the family of Industrial Engineering. As a limitation of the project described, it is recognised that a larger sample size would have enabled a more powerful analysis of the results.

Declaration of interests

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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