@tic revista d'innovació educativa
Vniversitat de València

Primavera (Enero-Junio 2017) Número 18. Págs. 13

Creative Project-based learning to boost technology innovation

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Fecha presentación: 03/10/2016 | Aceptación: 23/12/2016 | Publicación: 23/06/2017

Resumen
Este trabajo recoge los resultados de la aplicación de una metodología de aprendizaje basada en proyectos, mediante el uso mixto de aula inversa y sesiones magistrales participativas, junto con técnicas de creatividad y pensamiento lateral, para integrar los conceptos y procedimientos de la innovación tecnológica e impulsar capacidades propias del espíritu emprendedor entre los estudiantes de máster en Ingeniería Química. La alineación constructiva entre los resultados esperados y las habilidades de aprendizaje con las actividades propuestas y métodos de evaluación fue decisiva en el diseño de la metodología, donde la actividad tractora fue la creación y defensa de un proyecto de innovación. El uso de técnicas de creatividad promovió el pensamiento lateral y la originalidad en la definición de los proyectos. Se utilizaron metodologías activas para provocar el aprendizaje colaborativo, mejorar la participación y promover la motivación intrínseca. Las calificaciones obtenidas por todos los grupos en sus proyectos, a cargo de evaluadores externos, fueron relevantes, lo que indica la calidad y el impacto de sus propuestas. Se mostró una satisfacción general de los estudiantes, con especial énfasis en la trascendencia a nivel profesional, lo que demuestra el potencial de esta metodología para promover capacidades emprendedoras en innovación tecnológica.

Palabras clave: educación emprendedora; innovación tecnológica; aprendizaje basado en proyectos; aula inversa; creatividad; metodologías activas; metodologías colaborativas; evaluación.

Resum
En aquest treball es presenten els resultats de l'aplicació d'una metodologia d'aprenentatge basada en projectes, mitjançant l'ús mixt d'aula inversa i sessions magistrals participatives, així com tècniques de creativitat i pensament lateral, per a integrar els conceptes i procediments de la innovació tecnològica i impulsar capacitats pròpies de l'esperit emprenedor entre els estudiants de màster en Enginyeria Química. L'alineació constructiva entre els resultats esperats i les habilitats d'aprenentatge amb les activitats proposades i mètodes d'avaluació va ser decisiva en el disseny de la metodologia, on l'activitat tractora va ser la creació d'un projecte d'innovació. L'ús de tècniques de creativitat va promoure el pensament lateral i l'originalitat en la definició dels projectes. Es van utilitzar metodologies actives per provocar l'aprenentatge col·laboratiu, millorar la participació i promoure la motivació intrínseca. Les qualificacions obtingudes per tots els grups als seus projectes, a càrrec d'avaluadors externs, van ser rellevants, el que indica la qualitat i l'impacte de les seues propostes. Es va mostrar una satisfacció general dels estudiants, amb especial èmfasi en la transcendència a nivell professional, el que demostra el potencial d'aquesta metodologia per promoure capacitats emprenedores en innovació tecnològica.

Paraules clau: Educació emprenedora, innovació tecnològica, aprenentatge basat en projectes, aula inversa, creativitat, metodologies actives, metodologies col·laboratives, avaluació.

Abstract
This paper shows the results of the application of a project-based learning methodology that blended flipped classroom and face-to-face sessions, along with creativity and lateral thinking techniques, to integrate the expected concepts and procedures of technology innovation and boost entrepreneurship skills among students of Master's degree in Chemical Engineering. The constructive alignment between the expected learning outcomes and skills with the proposed activities and assessment methods was decisive in the design of the methodology, which tractor activity was the creation of an innovation project. The use of techniques of creativity promoted lateral thinking and originality in the

definition of projects. Active methodologies provoked team engagement and collaborative learning, enhanced participation and stimulated intrinsic motivation. The grades obtained by all groups in their projects given by external evaluators were relevant, thus pointing out the quality and impact of their proposals. There was a general satisfaction on students, with special emphasis of the transcendence at a professional level, thus showing the potential of this methodology to boost entrepreneurship skills in technology innovation.

Key Words: entrepreneurship education; technology innovation; project-based learning; flipped classroom; creativity; active methodologies; collaborative methodologies; assessment

1. Introduction

The promotion of entrepreneurship education (Fayolle & Gailly 2008; Gibb 2005) is of high interest and use in higher education schemes (Kuratko 2005). Entrepreneurship education has been traditionally focused on teaching individuals, but many initiatives are increasingly becoming more action-oriented, emphasizing learning by doing (Rasmussen & Sörheim 2006). Fostering entrepreneurship as a mindset is competency-based type of education, instructionally based on experiential learning (R.G. & MacMillan 2000), where experience is the source of learning and development (Kolb 2014). In this sense, contemporary entrepreneurship education is often based on a team-based challenge such as creating a new venture or solving a startup problem. A creative and professional solution to such a challenge requires both individual and team efforts (Harms 2015). Entrepreneurship education thus uses experiential learning (Kolb et al. 2000) as a means to potentiate critical thinking skills and decision-making attitudes (Solomon et al. 2002). This way the students are allowed to explore and outdare the limit of their knowledge, beliefs and representations, and therefore train their abilities to propose original solutions to what is unknown (Corbett 2005; Cooper et al. 2004). One of the most experiential learning to boost entrepreneurial skills is project-based learning (PBL) (Savery 2015). PBL drives the formative experience throughout an open-end project to change the paradigm of the teacher-centered teaching towards student-centered learning, which is expected to lead to a deep approach to learning (Marton & Säljö 1976). The key features of the PBL aim at fostering teamwork, critical thinking and skills related to interpersonal communication and project management (Helle et al. 2006). By learning through projects and teamwork, students move from merely listening and reading about abstracts towards working with their teammates in the utilization of those concepts and procedures to solve real-world problems (Michaelsen et al. 2014).

An adequate implementation of PBL implies a higher level of students' independence and decision-making, thus reducing the importance of the taught contents, i.e. transmitted, and devote efforts to propose motivating and relevant activities in class. In order to permit the best development of PBL, the learning environment has to be designed in a rich, complex and dynamic manner that invites interaction with different agents and fosters deep understanding. The learning environment should also include innovative technologies that can be used to achieve educational goals and improve the quality of the learning processes (Bransford et al. 2000). In this sense, PBL and flipped classroom, as complementary models, perfectly fit. Under the flipped classroom (Baker 2000; Lage, M. J.; Platt et al. 2000), the lectures are moved towards an online platform to be studied before class, whereas time in class is dedicated to learning activities that require students to engage concepts at high levels in Bloom's taxonomy, i.e. create, evaluate and analyze, in contrasts to lower cognitive levels such as remembering, understanding and applying, which can be worked in advance. Some examples of the application of flipped classroom are reported for diverse subjects such as microeconomics (Lage, M. J.; Platt et al. 2000), software engineering (Gannod et al. 2008), physics (Bates & Galloway 2012), business (Schullery et al. 2011) or statistics (Strayer 2012). Comprehensive reviews can be found in literature for further reading (Lowell Bishop & Verleger 2013; O'Flaherty et al. 2015).

Although the introduction of flipped classroom would benefit from an institutional strategy in which all members of the university community should be involved (Kolb & Kolb 2005), it still remains a discrete vocational option among instructors. The flipped classroom model has the potential to enable teachers to cultivate critical and independent thought in their students, building the capacity of life-long learning and thus preparing future graduates for their workplace contexts (O'Flaherty et al. 2015). Indeed, the flipped paradigm benefits from: (i) more one on one time with students; (ii) opportunities for active and collaborative learning; (iii) less missed lectures; (iv) self-paced learning; and (v) “just-in-time” type instruction. Current educational approaches in higher education perform blended learning; where students receive a combination of traditional face to face (F2F) instruction in class and are also previously required to complete activities outside of the class, facilitated through a range of on-line instructional resources(Bonk & Graham 2012). Blended learning has become increasingly popular in higher education (Lage, M. J.; Platt et al. 2000). Several experiences with blended learning can be found in literature (Picciano et al. 2013). Actually, flipped learning can be therefore considered a complement, rather than a substitute, to the traditional classroom of teachers' speeches, since it allows classroom time to be geared more towards active and collaborative learning (Roach 2014).

A key to stimulate entrepreneurship skills through innovation is the training of creativity in project-based learning. Creativity in organizations as a phase of innovation is a crucial issue at the core of systems. In the area of economics and management, auditing the creative process is acknowledged to ensure the longevity and competitiveness of companies (Fischer et al. 2015). Therefore, it might be worthy to apply creative methodologies in other educational spheres such as engineering, which mainly addresses the technological development of goods and processes. Several techniques to train creativity can be found in literature (Birdi 2015). Creativity can impregnate the actions of generation and evaluation of ideas by promoting lateral thinking (De Bono 2010), using techniques of imagination, analogies or decomposition, among others. Combining creativity and innovation can therefore enhance positive emotions through an increase in autonomy (Bujacz et al. 2016), essential to promote

entrepreneurship skills. Furthermore, the combination of the implementation of creativity techniques, supported by the use of technological resources, under active learning models such as flipped classroom, is understood as an opportunity to engage millennial students in their own life-long learning process (Roehl et al. 2013).
The courses have to be constructively aligned, in order to connect the desired outcomes with consistent teaching and learning activities and appropriate assessment requirements (Biggs & Tang 2007). Therefore, the aim of this work was to implement a project-based learning strategy experienced on a blended learning teaching model, promoting collaborative attitudes and creativity abilities to stimulate technology innovation and entrepreneurship skills at an engineering master level.

2. Methodology

2.1. Context

This work focused on the Thematic Section of Innovation of the newly created subject Comprehensive management of quality, safety and innovation of the Master's Degree in Chemical Engineering at the School of Engineering of the University of Valencia during the 2015-16 academic year. This is a compulsory transversal subject of the first semester with a load of 4.5 ECTS, which consists in 3 distinct thematic blocks in which the subject is structured - see Quality management; Industrial safety and risk prevention; and Innovation-. The Thematic Section of Innovation dedicated 1.5 ECTS. The face-to-face sessions were divided into 4 sessions of 3 hours (S1,S2,S3,S4) and 1 session of 2 hours (S5), leaving 1 hour for the exam. The quantification of non-attending hours considered a 150% factor, divided into 6.5 h for individual work and preparation of practical sessions, 4 hours for the preparation of the exam and 10 hours for the development of a group work. It was taken by 19 students, most of them coming from the Degree in Chemical Engineering.

2.2. Design of the methodology

The general aims of the Thematic Section of Innovation were to show and practice the key concepts of innovation schemes, financing of research, development and innovation (RDI), technology transfer and intellectual and industrial property rights. In order to integrate the contents of the subject in a motivating creative experience, a project-based learning model was proposed, through which the students were organized into groups of 3/4 students to work on their own innovation project in Chemical Engineering (from now on, CE-Innovation project). The framework of the CE-Innovation project was *bioeconomy*, the trendy topic in the European Innovation Program Horizon 2020 to refer to circular economy and technological innovations in the fields of products coming from renewable resources, reduction of pollution and waste and processes with high energy efficiency. This topic was wide enough and affordable for students according to their previous knowledge, due to their background in engineering.
As a deliverable of the work, the students should prepare and defend a poster and a digital video in a public session simulating a professional workshop, with a multi-profile external assessment board. The contents of the poster answered to the outcomes of every face-to-face session, which were structured in terms of simulated departments at RDI organisms, as a way to resemble the camp model for entrepreneurship education (Bager 2011), in which at each session the students got a different role and a different aim at specific departments. The knowledge of systems of innovation and decision of RDI projects was framed in the RDI Strategic Department at session 1. Afterwards, all activities related to information and communication were arranged at the Technological Watching Department at session 2. In addition, all the possibilities of financing research projects were considered at the Financing / Projects Department at session 3. Finally, the concepts of protection and exploitation of RDI results were tackled at the Valorisation of RDI Department at session 4. Figure 1 shows a scheme of the design of the poster as a deliverable of the CE-Innovation project in relation with the different contents and activities held at every face-to-face session. In order to optimize the face-to-face sessions with cognitive activities of high level in the categories of analysis, evaluation and creation of Bloom's taxonomy, a flipped classroom model was implemented. The students worked the necessary contents and activities of low level in the categories of remembering, understanding and applying, previously to the face-to-face sessions, with the support of the resources available at the e-learning platform based on *Moodle*. The teacher abandoned the teaching suit to become a mentor, in order to persuade and engage the students to build and strengthen an entrepreneurial social identity among the group (Lefebvre & Redien-Collot 2013).In addition, to promote active and collaborative attitudes towards learning, several methodologies and resources were used. Finally, the use of several techniques of creative generation and evaluation of ideas to boost technology innovation and entrepreneurship skills among the students are highlighted.

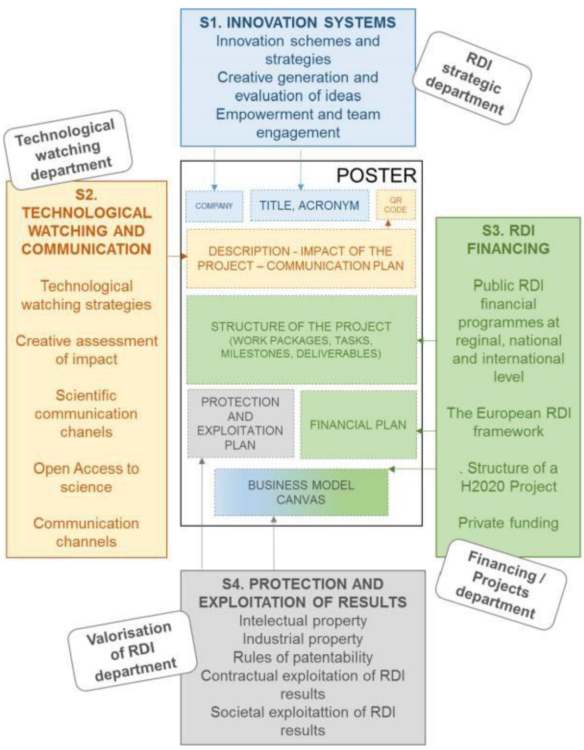

Figure 1. Design of the Thematic Section of Innovation around a project of technological innovation

2.3. Description of sessions

In the present section, the different face-to-face sessions are described in terms of constructive alignment between expected learning outcomes, activities at the flipped and face-to-face classrooms, as well as active and collaborative methodologies, techniques of creativity and digital resources used to build up knowledge and skills around the CE-Innovation project.

2.3.1. RDI Strategic Department

Under this professional role, the students were expected to be able to stablish differences among different innovation schemes and to apply methodologies of creativity to boost technology innovation. In particular, the aim of this session was to build the seed of the future CE-Innovation project.
The contents given during the flipped classroom were the exposition of the subject itself, along with references to the motivation of the CE-Innovation project in the field of bioeconomy or circular economy. As an activity, the students should tweet 3 messages with the hashtag #yoiqinnovo [1] answering to the following question, i.e. creative object: *Which technological innovation in the framework of bioeconomy would you propose to change the world?* This way the students started to engage with the subject and the innovation was triggered.
During the face-to-face session, an initial active discussion based on a visual-thinking tool such a word-cloud of concepts related to innovation triggered the introduction of the subject around the historical evolution of the innovation schemes. Afterwards, the students participated in a session of creative generation of ideas (Figure 2), in which several creativity techniques were combined (Michalko 2006). Firstly, brainswarming, understood as a silent and written brainstorming with the advantages of avoiding ruling voices and therefore more participative, was performed in combination with the SCAMPER technique, which is the acronym for substitution, combination, adaptation, modification, potentiation, elimination and reordering, and allowed the generation of more than 300 ideas in 30 min at the group of study. Afterwards, three different techniques of creative evaluation were used. Firstly, the ideas were passed through the funnel of the PAI criteria -i.e. "Potential", "Attractive" and "Interesting"-, according to the foreseen period of time to put the idea in practice. At that moment, the groups were spontaneously formed according to their choice of potential ideas. In contrast to traditional free group formation, which might consider aspects such as friendship or affinity, it must be mentioned that no changes in teams were considered though the students were given the chance to change groups and/or ideas of projects, thus the strength of identification with their own build-up ideas was relevant. Once the idea was converted into a seed project, the technique of the six thinking hats (De Bono 1989), which is a decomposition technique that permits the analysis of ideas under different perspectives, in combination with a creative SWOT (Badia, Teruel-Juanes, et al. 2016), a matrix which considers internal factors such as Strengths, Weaknesses, as well as external Opportunities and Threats, was applied to sieve, polish and redefine the project in a more mature state.

[1] (in Spanish, iq= ingeniería química, while in English, ce=chemical engineering. Hashtag in English would be #iceinnovate)

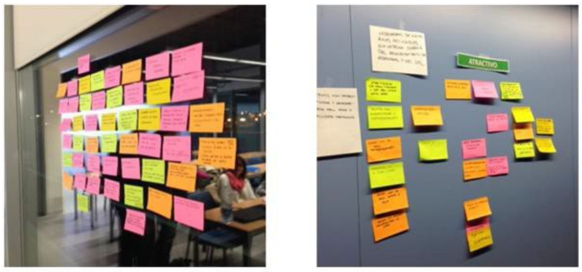

Figure 2. Example of session of creative generation of ideas through brainswarming+SCAMPER (left) and funnel of ideas through PAI criteria (right)

The results of this session on the CE-Innovation project were (i) the definition of the title of the project answering to the idea of technology innovation, (ii) the team formation and engagement through the simulated foundation of their companies, along with the description of their scope; and (iii) the identification of the students with their CE-Innovation projects through the consensual naming by means of an acronym.

2.3.2. Department of Technology watching and communication

Under this professional role, the students were expected to identify the sources of specialised information in the framework of chemical engineering, in order to compare the state of the art or technique of different technological innovations, and to be able to formulate the impact of an innovation in the framework of sustainability, being considered as the intersection of the spheres of people (societal, political), profit (economic) and planet (environmental). In particular, the aim of this session was to work with the combination of technological watching, communication and impact as a holistic approach to focus the technical viability of the CE-Innovation project.
The contents learnt previously to the face-to-face session corresponded to the cycle and sources of technological watching, with special focus on the detection of sources of scientific publications and technological patents, along with the overview of the innovation state and lines of research of the surrounding RDI organisms, giving therefore real, close and approachable examples to the students. As well, the students started working on the plan of technological watching with the help of a shared text document to be collaboratively filled in on-line.
At the face-to-face session, the students finished the setting of the plan of technological watching. As well, the students practiced with the search of scientific journals, along with their classification according to indexing parameters such as the impact factor or the quartiles. In addition, they also compared the scientific profiles of researchers in terms of h-index (Hirsch & Buela-Casal 2014). Afterwards, the students practiced how to find out the politics of open access for publications at specific scientific journals. Finally, a technique of creativity based on visual thinking and the development of lateral thinking by decomposition, the so-called spiral of thoughts, was applied to define the impact of the CE-innovation project. The results of this session on the CE-Innovation project were (i) the diagnosis and description of the impact and (ii) the definition of the communication plan.

2.3.3. Department of Financing and RDI Projects

Under this professional role, the students were expected to identify the most important organisms of innovation at national and international level, to structure the key concepts of a research project, to be able to detect the calls of public financing for RDI and to distinguish among private financing resources according to the degree of development of the innovation. In particular, the aim of this session was to choose the appropriate financing resources at the stages of proof of concept, prototype and product of the CE-Innovation project and to define its structure in a box diagram according to the main work-packages and tasks.

The contents taught previously to the face-to-face session were the types of financing RDI in terms of projects, staff, capabilities and internationalisation and the definition of the societal challenges of the European Program of Innovation Horizon 2020. As activity, the students searched at the particular portals at university, regional, national and European levels of financing for RDI and selected one program of each case to be discussed in class.

At the face-to-face session, the students performed a summary of financing programs by means of the active methodology Aronson's puzzle or puzzle of experts (GIIMA 2008), aided by a collaborative presentation file. As well, the different options for private financing for RDI were discussed. Finally, a creative technique which uses analogies was applied to define the structure of the CE-Innovation project. The groups alternatively assumed three roles which permitted covering the structure from different perspectives of the so-called in business *dream team*, which represent the ideal profiles of a group. It was formed by the *shark*, which is in charge of snooping the market, perform the benchmarking and locate the niche of the innovation; the *hipster*, which is in charge of achieving the attractiveness of the project and therefore pay attention to its impact; and the *hacker*, which is in charge of the internal functioning of the project, and therefore take care of the technical structure.

The results of this session on the CE-Innovation project were (i) the visual structure of the project and (ii) the definition of the financial plan.

2.3.4. Department of Protection and Exploitation of RDI results

Under this professional role, the students were expected to distinguish between contractual and societal exploitation of RDI results, and to be able to assess the state of a technological innovation according to the rules of patentability. In particular, the aim of this session was to design the strategy of protection and exploitation of the expected RDI results of the CE-Innovation project.

The contents worked during previously to the face-to-face session considered the routes of knowledge transfer and, in particular, the options of societal and contractual technology transfer.

At the face-to-face session, tough contents such as the distinction between intellectual and industrial property rights, as well as the features and rules of patentability were discussed with the help of online quizzes with the e-tool *Socrative*. Quizzes were answered by means of their mobile devices, taking advantage of the Bring Your Own Device (BYOD) possibilities to perform questions to the whole class and gather the collective and individual answer as well as to offer instant feedback, being relevant in terms of ensuring comprehension and integration of concepts (Badia, Navarro, et al. 2016). Finally, the students worked in a collaborative manner with the help of mind-mapping tools such as *Cmap Tools* or shared text files to establish the results of this session, which were (i) the plan of protection and exploitation of RDI results, and (ii) the summary of the CE-Innovation project on a Business Canvas Model, in order to cover the variability of perspectives of potential audience interested in their innovations.

2.3.5. Summary

Figure 3 schematises the relationship between learning outcomes of the Thematic Section of Innovation, structured across the different sessions, with division between contents and activities performed previously to the face-to-face session and activities worked during the face-to-face sessions. The active methodologies, creativity techniques and digital resources used to support the learning process are highlighted as well.

EXPECTED LEARNING OUTCOMES	SESSIONS	FLIPPED CLASSROOM	ACTIVITIES AT SESSION	ACTIVE METHODOLOGIES, CREATIVITY TECHNIQUES AND DIGITAL RESOURCES
To stablish differences among different innovation schemes	S1. INNOVATION SYSTEMS	Trigger of innovation	To argue the historical evolution of the innovation schemes	Active discussion triggered by a word cloud
To apply methodologies of creativity to boost technology innovation		Exposition of the subject	To participate in a creative generation of ideas	Collaborative Brainswarming + SCAMPER
		Engagement of teams	To participate in a creative evaluation of ideas	Collaborative PAI criteria, six hats, and creative SWOT
To identify the sources of specialised information in the framework of chemical engineering	S2. TECHNOLOGICAL WATCHING AND COMMUNICATION	Cycle of technological watching	To set the plan of technological watching to nurture the scientific-technical basis of the CE-Innovation project	Collaborative discussion with the help of a shared text file
To compare the state of the art or technique of different innovations		Identification of potential research groups and institutions	To practice with the processes of scientific publications, indexers and databases and search in Open access journals	Advanced search through scientific databases
To formulate the impact of a innovation project in the PPP framework (People, Profit, Planet)		System of alerts of technological watching	To describe the impact according to the sustainability PPP framework by a creative mind-mapping method	Collaborative spiral of thoughts with the help of mind-mapping tools
To identify the most important organisms of innovation at national and international level	S3. RDI FINANCING	The map of innovation in Spain	To distinguish among criteria of public financing	Active discussion
To structure the key concepts of a research project		Types of financing for RDI	To distinguish between the different actors of private financing according to the state of development of the CE-Innovation project	
To detect the calls for financing RDI activities		Regional, national and European public financing organisms and programmes	To set the plan of financing of the CE-Innovation project	Aronson's puzzle of experts, with the help of shared presentation files
		The challenges of society in financed science	To describe the CE-Innovation project in terms of work packages, tasks, deliverables and milestones	
To distinguish among the private financing resources available for innovation		Eligible costs at RDI projects	To identify potential partners to setup consortia to run the CE-Innovation project	The dream team: hipster, hacker and shark
To distinguish between contractual and societal exploitation of RDI results	S4. PROTECTION AND EXPLOITATION OF RDI RESULTS	Routes in knowledge transfer	To distinguish between intellectual and industrial property rights	Active discussion promoted by BYOD questionnaires
To assess the state of an innovation according to rules of patentability		Society technology transfer	To apply the rules of patentability to the CE-Innovation project	
To design a strategy of protection and exploitation of RDI results		Contractual technology transfer: structure of contracts	To establish the plan of protection and exploitation of RDI results	Collaborative discussion with the help of mind-mapping tools
			To perform a Business Model Canvas	
To be able to integrate concepts and procedures of innovation in a project	S5. MY CE-INNOVATION PROJECT	Transversal Session dedicated to collaborative and critic skills		

Figure 3. Alignment between learning outcomes and designed activities

See enlargement of the figure 3 in Annex 1

2.4. The CE-Innovation project

2.4.1. The CE-Innovation project as a trigger for skills

The CE-Innovation Project conceived as the tractor project of the subject was designed to enhance the opportunities of acquisition of basic (B), general (G), transversal (T) and specific (S) skills, as shown in Figure 4. In general terms, skills concerning the relative perception of the students in their surroundings, the capabilities of life-long learning, the self-critic abilities, responsibility, and communication and diffusion were considered.

SKILLS	How did the CE-Innovation Project contribute to acquire it?
B1. Students can apply the knowledge acquired and their ability to solve problems in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their field of study. S1. Adapt to structural changes in society caused by economic, energy or natural factors or phenomena in order to solve resulting problems and provide technological solutions with a high commitment to sustainability	The framework of the CE-Innovation Project was wide enough to cover all the technological fields a chemical engineer could be involved in, in a multidisciplinary view, combining knowledge from different disciplines. In particular, it was aligned with the current societal challenges of the European program of innovation in bioeconomy, which involves sustainability.
B2. Students are able to integrate knowledge and handle the complexity of formulating judgments based on information that, while being incomplete or limited, includes reflection on social and ethical responsibilities linked to the application of their knowledge and judgments. T1. Be able to access information tools in different areas of knowledge and use them properly.	The development of the CE-Innovation Project was based on a technological watching strategy that should be followed to cope with the necessary background to explain the technological innovation. In addition, one of the dimensions of the definition of the impact is the perspective of benefits for individuals, organizations and societies. As well, along the course, the students were taught different digital resources and online databases to prevent them from infoxication during the information search.
B3. Students have the learning skills that will allow them to continue studying in a way that will be largely self-directed or autonomous. T2. Be able to take responsibility for their own professional development and specialisation in one or more fields of study. T3. Have skills for independent learning in order to maintain and enhance the specific competences of chemical engineering, which enable continuous professional development. T4. Be able to assess the need to complete their technical, scientific, language, computer, literary, ethical, social and human education, and to organise their own learning with a high degree of autonomy.	The CE-Innovation Project itself, as tractor project, motivates the habit of learning by doing. As well, each session offers ways to extent the specialization of the students depending on their preferred roles. The flipped classroom permits self-paced learning and therefore to organize their own learning, helped with instant on-line feedback and posterior face-to-face feedback.
B4. Students have the knowledge and understanding that provide a basis or an opportunity for originality in developing and/or applying ideas, often within a research context. G1. Conduct proper research, undertake the design and lead the development of engineering solutions in new or unfamiliar environments by linking creativity, originality, innovation and technology transfer. G2. Adapt to changes and be able to apply new and advanced technologies and other relevant developments with initiative and entrepreneurship. S2. Manage research, development and technology innovation taking into account the transfer of technology and the property and patent rights.	The CE-Innovation Project was based on the result of the combination of creative generation and evaluation of ideas, which could be used to consider originality of innovations in different technologies. Innovation and technology transfers were the skeleton of the contents and framework of the development of the CE-Innovation Project. The entrepreneurship was promoted by the development of the CE-Innovation Project from the economic perspective, on the one hand, and on the competitive perspective, on the other hand.
G3. Communicate and discuss proposals and conclusions in specialised and non-specialised multilingual forums, in a clear and unambiguous manner. T5. Be able to defend criteria with rigor and arguments and to present them properly and accurately.	The CE-Innovation Project was defended at a public forum to different assessment boards composed by teachers, students and entrepreneurs.

Figure 4. Relationship between basic (B), general (G),

transversal (T) and specific (S) skills and features of the CE-project considered to acquire them
See enlargement of the figure 4 in Annex 2

2.4.2. Deliverables of the CE-Innovation Project

The deliverables of the CE-Innovation Project were (i) a poster with all the contents developed during the previous sessions as shown in Figure 1: and (ii) a short video to catch the attention of the audience, with special stress on the impact of the technological innovation. This video should be uploaded to a webpage and the link coded in a QR code to be included in the poster in order to multiply the impact of their innovations a posteriori, since the posters were afterwards hung at different classrooms of the Chemical Engineering Degree.
The deliverables were presented and defended at a Workshop of CE-Innovation prepared at session 5, one month after the face-to-face sessions, organized to simulate a real scientific or technical event for the students so as to put their communication skills in practice.
In order to evaluate the innovations, an assessment committee of 22 members composed by teachers of the department of chemical engineering, students of the degree of chemical engineering, teachers of innovative education and entrepreneurs was setup. The innovations could be assessed from different perspectives and, even more, the students had the chance to rephrase their speeches adapting the message to the different profiles of audience.

2.4.3. Design of the assessment of the CE-Innovation Project

Figure 5 schematises the different elements taken into consideration for the assessment of the CE-Innovation project, which are explained in the following sub-sections.

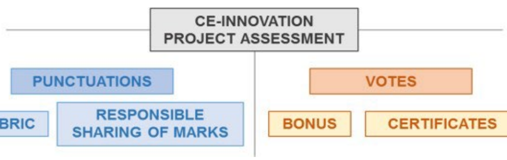

Figure 5. Elements for the assessment of the CE-innovation project

Rubric of assessment.
Figure 6 shows the rubric handed to the assessment board. This rubric was shared with the students one month in advance, being invited to propose amendments. No modifications were claimed, thus all criteria and weighs were accepted . The poster was assessed in terms of quality, clarity and originality. The video was evaluated in terms of accessibility, quality and impact. Finally, the qualifications of the defence considered the quality of the content and the defence, the enthusiasm and the outfit. It should be mentioned that the teacher of Innovation did not participate in the assessment, since it was considered that the teacher must coach the groups and participate as external observer during this session.

Responsible sharing of marks.
In order to ensure that the collaborative work was efficient and worthy, and mainly to offer the chance to students to be responsible with their real effort in reference to the rest of the group, the mark of the project was multiplied by the number of participants and then this global mark shared among the individuals according to the criteria set out in the group. For example, a mark of 8 in the CE-Innovation Project for a group of 3 people would generate a global mark of 3X8=24, which could be shared as 8-8-8, 7-8-9, 7-7-10, etc… In order to obtain the relative distribution of their marks, before the defence, the students delivered a document in which 120 points (in order to be valid for groups of 3 or 4 students) were distributed according to their own criteria.

Certificates of votes.
With the aim of enhancing the intrinsic motivation of students and fair competence, and to reward their effort in the elaboration of the CE-Innovation Project, the assessment board had to give a vote to the following categories: (i) Best CE-Innovation project; (ii) Best communication plan and video; (iii) Best technology transfer model ; (iv) Best business model. Afterwards, the students were given a certificate with the achieved merits that they could use in their curricula, being therefore an extra value for their records.

Bonuses from votes.
Apart from the certificates, the students could obtain between a 5% and a 10% increment on their marks at the exam of the thematic section of innovation.

	CATEGORY	4	3	2	1
POSTER (40%)	Design and attractiveness (50%)	The poster is exceptionally attractive in terms of design, distribution and order.	The poster is attractive in terms of design, distribution and order	The poster is relatively attractive though it may be a bit cluttered.	The poster is quite messed up or is very poorly designed. It is not attractive.
	Figures-relation and clarity (25%)	All the figures are related to the theme and make it easy to understand	All the figures are related to the topic and most make it easy to understand.	All the graphs are related to the topic although it is difficult to understand the relationship.	Figures do not relate to the topic
	Figures-Originality (25%)	Many of the figures used in the poster reflect an exceptional degree of creativity of the team in its creation and/or exposure.	One or two of the figures used in the poster reflect the creativity of the team in its creation and/or exposure	The figures are made by the team, but are based on the design and ideas of others	There are no figures made by the team
VIDEO (10%)	Quality (40%)	The quality of the digital element and the approach (in the case of video) was excellent in all its parts.	The quality of the digital element and the approach (in the case of video) was excellent in most of the video.	The quality is OK but it could be improved in the majority of the digital item.	The quality is not very good
	Accessibility (20%)	I can access the digital element easily from my mobile device with a QR-reader	I can access the digital element with difficulty from my mobile device with a QR-reader	I can not access the digital element easily from my mobile device even with a QR-reader	I can not access the video with a QR-reader
	Impact (40%)	The content of de digital element appeals to me, I want to know more about the project. Also very good quality	The content of de digital element appeals to me, I want to know much more about the project, but it could have worked more quality	The content of de digital element scarcely attracts me, and the quality is questionable	The content of de digital element fails to attract my attention. In addition, it was performed with very poor quality
DEFENSE OF THE WORK (50%)	Content (40%)	It demonstrates a full understanding of the subject, and motivations of each election	It shows a good understanding of the subject, but I find it difficult to understand motivations of some sections.	It shows a good understanding of parts of the topic. However, they struggle to explain the motivations of many of the choices made.	It does not seem to understand very well the theme or transmit the motivations of each choice
	Defence/interview (30%)	The team can answer precisely all the questions related to the facts in the poster and the processes used to create it.	The team can accurately answer most of the questions related to the facts in the poster and the processes used to create it	The team can answer accurately approximately 50% of the questions related to the facts in the poster and the processes used to create it	The team doesn't seem to have knowledge of the facts or the processes used in the creation of the poster
	Enthusiasm (20%)	Facial expressions and body language generate strong interest and enthusiasm about the topic elsewhere	Facial expressions and body language sometimes generate strong interest and enthusiasm about the subject elsewhere	Facial expressions and body language are used to try to generate enthusiasm, but seem to be trumped.	Very little use of facial expressions or body language. It does not generate much interest in the way of presenting the topic
	Outfit (10%)	Appropriate business outfit	Proper, although casual business outfit	Casual, although neglected business outfit	The outfit is not, in general, suitable for audience

Figure 6. Assessment rubric given to the assessment board

3. Results and discussion

3.1. Performance of the workshop of CE-Innovation

6 works were presented at the Workshop of CE-Innovation. Figure 7 shows the layouts of the posters presented by the students, which tackled the following diverse technological innovations:

- BACTILUZ: detection of heavy metals in industrial waters by bioluminescent bacteria.
- BIOBAGS: Highly - strength biodegradable bags
- BIOGRAPHERE: Purification of air by microorganisms encapsulated in spheres of graphene
- BRICKFUEL: Obtaining of bio-fuel from wasted tetra-bricks
- ECO-PC: Development of fully eco-based personal computers.
- NEUIMPACT: Asphalts with low impact in tyres

The QR code in
Figure 7 links to a video which summarises the development of the workshop showing the explanations of the CE-innovation projects in the format of elevator pitch –i.e., short synthetic speeches highlighting the main impact-. This video was also published at the webpage of the master and served as motivating element for students of the Grade of Chemical Engineering and as a claim for new students.

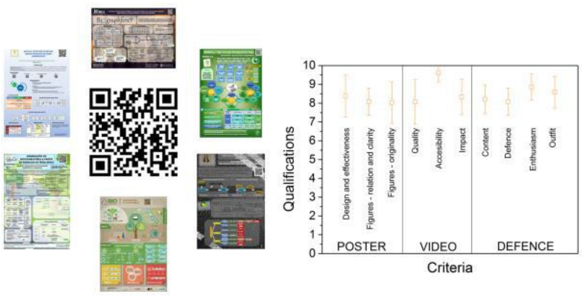

Figure 7. Left: Poster of the CE-projects presented at the workshop and QR code to access a summary video. Right: Results of the assessment of the CE-Innovation project according to the different criteria for the evaluation of the poster, the video and the defence.

Figure 7 also shows the results of the assessment of the CE-Innovation project by the external evaluation board, according to the different criteria for the evaluation of the poster, the video and the defence, in the terms raised at the rubric shown in Figure 6.. An average of nearly 8,5 points was obtained by all groups, regardless the profile of the evaluators in the assessment board, therefore showing the relevance, quality and impact of their technological innovations.

3.2. Assessment of satisfaction

An on-line quiz shown in annex 3, which considered the satisfaction of the students according to technological, collaborative, methodological and transcendental dimensions, was performed with the help of the e-tool *Socrative* and answered by all students. The questions considered the opinion of students in terms of the appropriateness or degree of satisfaction based on a Likert scale, from 1 (completely disagree) to 5 (completely agree). Results are shown in the following sub-sections.

3.2.1. Assessment of technological dimension

Under this dimension, the interest was focused on the utility and accessibility of the virtual platform used to support the course, based on *Moodle*. As well, the students were asked about the support resources -i.e., videos, activities, documents, links, forums - in terms of format, quality and utility. Figure shows the cumulative counts and relative percentages of the results based on a Likert scale Most of the students showed satisfaction in all categories, highlighting the complete satisfaction with the format and utility of the support resources, which mainly built up the basis for the flipped classroom.

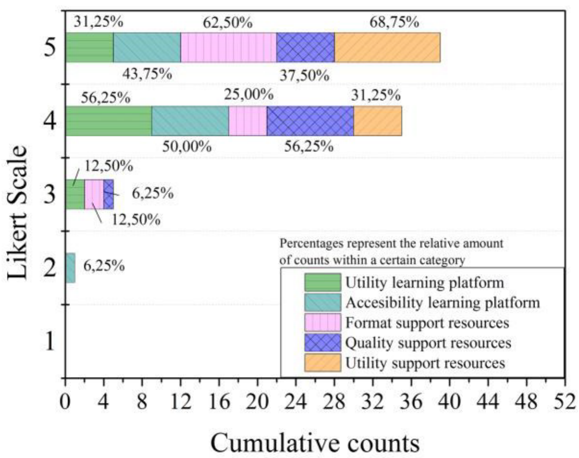

Figure 8. Results about satisfaction on virtual learning platform and digital resources

3.2.2. Assessment of collaborative dimension

Under this dimension, the interest was focused on the cooperation, in terms of management and effectiveness, as well as their impression of using collaborative methodologies to improve the quality of the CE-innovation projects and to develop their skills. Figure shows the cumulative counts and relative percentages of the results based on a Likert scale, which highlighted a successful perspective towards collaborative learning, with special perception of a positive impact on the skills of students.

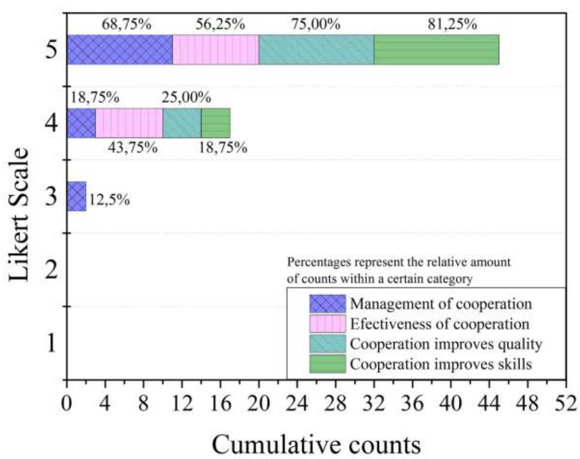

Figure 9. Results about satisfaction about collaborative learning

3.2.3. Assessment of methodological dimension

Under this dimension, the interest was focused on the utility of the flipped classroom and the project-based learning strategies, and their impact on motivation and participation. Figure shows the cumulative counts and relative percentages of the results based on a Likert scale. The results are in agreement with those found in literature in which after experiencing a flipped classroom approach, the students became more positive towards this learning model (Butt 2014). As well, the results showed how the participation and motivation were relevant ingredients for a successful project-based learning.

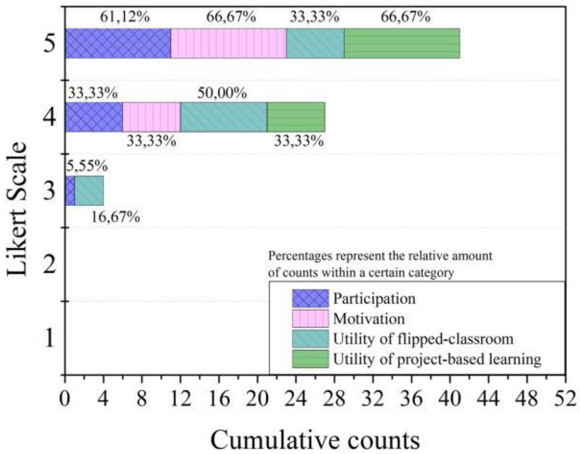

Figure 10. Results about satisfaction on project-based learning and flipped classroom

3.2.4. Assessment of transcendental dimension and entrepreneurship

Under this dimension, the interest was focused on the impression of professional transcendence (i.e. how the trained skills can be useful in a near future at a professional sphere) of the creative project-based learning due to the role-play developed at every face-to-face session, along with the transcendence of the methodology itself in terms of satisfaction and furthermore willingness of recommendation.

Figure shows the cumulative counts and relative percentages of the results based on a Likert scale, highlighting the relevance of the methodology to move professional attitudes and perspectives. The quantification of the success of entrepreneurship at university level is hard to evaluate since neither companies nor technological ventures were expected to be created immediately after the application of the course. Nevertheless, it should be remarked that three out of six groups participated in the university MOTIVEM program of the University of Valencia (Cátedra de Cultura Empresarial Universitat de València 2016), a competition of ideas at the think tank stage, which is linked to a formative program to continue developing their entrepreneurship skills. As a whole, experiential learning under different professional roles, in a continuous team work, with high cognitive thinking skills and decision-making attitudes will help develop entrepreneurship skills for future competent specialists.

Altogether, there was a general satisfaction with the methodology and all students partially or completely agreed to recommend the application of the methodology in other subjects.

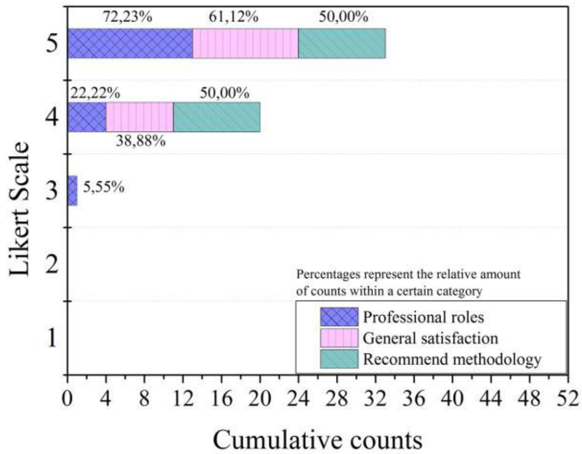

Figure 11. Results of general satisfaction and professional transcendence

4. Conclusions

A blended and creative project-based learning methodology that combined flipped classroom and face-to-face sessions was applied to integrate the expected concepts and procedures of technology innovation and boost entrepreneurship skills among Master degree students of chemical engineering.

The methodology conceived an Innovation Project as the tractor of the subject which considered the acquisition of skills concerning the relative perception of the students in their surroundings, capabilities of life-long learning, self-critic abilities, responsibility and communication skills. Due to the multidisciplinary design of the learning experience, several added-value outcomes can be highlighted:

(I) The use of techniques of creativity stimulated lateral thinking and originality in the definition of innovation projects.

(II) Active methodologies provoked team engagement and collaborative learning, enhanced participation and promoted intrinsic motivation.

(III) The combination of flipped classroom, techniques of creativity and active methodologies structured throughout an Innovation project permitted the constructive alignment between expected learning outcomes and skills with the proposed activities and assessment methods.

(IV) The teacher acted as a mentor, so as the grades obtained by all groups in their projects were given by external evaluators. The relevance of their marks pointed out the quality and impact of their proposals, thus boosting motivation and reaffirming the value of their effort.

There was a general satisfaction of students on the creative project-based methodology at all considered dimensions, i.e. technological, collaborative, methodological and transcendental. In particular, there was a relevant satisfaction with the Innovation course, with special emphasis of the applicability at a professional level, thus showing the potential of this methodology to boost entrepreneurship skills in technology innovation.

Acknowledgements

The authors acknowledge the support of the Vice Rectorate for Policy Training and Educational Quality of the University of Valencia, through the IDIQ - METTIC project (UV - SPFIE_RMD15-314415) and the IDIQ-YOIQINNOVO project (UV-SFPIE_RMD16-415615. The High Technical School of Engineering and the Department of Chemical Engineering of the University of Valencia are thanked for logistic and economic support.

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| Cita recomendada de este artículo

Badia, José D.; Martínez Soria, Vicente. (2017). "Creative Project-based learning to boost technology innovation". en *@tic. revista d'innovació educativa.* Número 18. Primavera (Enero-Junio 2017), pp. 1-13.

Annex 1

Figure 3. Alignment between learning outcomes and designed activities

EXPECTED LEARNING OUTCOMES	SESSIONS	FLIPPED CLASSROOM	ACTIVITIES AT SESSION	ACTIVE METHODOLOGIES , CREATIVITY TECHNIQUES AND DIGTAL RESOURCES
To stablish differences among different innovation schemes	**S1. INNOVATION SYSTEMS**	Trigger of innovation	To argue the historical evolution of the innovation schemes	Active discussion triggered by a word cloud
To apply methodologies of creativity to boost technology innovation		Exposition of the subject	To participate in a creative generation of ideas	Collaborative Brainswarming + SCAMPER
		Engagement of teams	To participate in a creative evaluation of ideas	Collaborative PAI criteria, six hats, and creative SWOT
To identify the sources of specialised information in the framework of chemical engineering	**S2. TECHNOLOGICAL WATCHING AND COMMUNICATION**	Cycle of technological watching	To set the plan of technological watching to nurture the scientific-technical basis of the CE-Innovation project	Collaborative discussion with the help of a shared text file
To compare the state of the art or technique of different innovations		Identification of potential research groups and institutions	To practice with the processes of scientific publications, indexers and databases and search in Open access journals	Advanced search through scientific databases
To formulate the impact of a innovation project in the PPP framework (People, Profit, Planet)		System of alerts of technological watching	To describe the impact according to the sustainability PPP framework by a creative mind-mapping method	Collaborative spiral of thoughts with the help of mind-mapping tools
To identify the most important organisms of innovation at national and international level	**S3. RDI FINANCING**	The map of innovation in Spain	To distinguish among criteria of public financing	Active discussion
To structure the key concepts of a research project		Types of financing for RDI	To distinguish between the different actors of private financing according to the state of development of the CE-Innovation project	
To detect the calls for financing RDI activities		Regional, national and European public financing organisms and programmes	To set the plan of financing of the CE-Innovation project	Aronson's puzzle of experts, with the help of shared presentation files
		The challenges of society in financed science	To describe the CE-Innovation project in terms of work packages, tasks, deliverables and milestones	
To distinguish among the private financing resources available for innovation		Eligible costs at RDI projects	To identify potential partners to setup consortia to run the CE-Innovation project	The dream team: hipster, hacker and shark
To distinguish between contractual and societal exploitation of RDI results	**S4. PROTECTION AND EXPLOITATION OF RDI RESULTS**	Routes in knowledge transfer	To distinguish between intellectual and industrial property rights	Active discussion promoted by BYOD questionnaires
To assess the state of an innovation according to rules of patentability		Society technology transfer	To apply the rules of patentability to the CE-Innovation project	
To design a strategy of protection and exploitation of RDI results		Contractual technology transfer: structure of contracts	To establish the plan of protection and exploitation of RDI results	Collaborative discussion with the help of mind-mapping tools
			To perform a Business Model Canvas	
To be able to integrate concepts and procedures of innovation in a project	**S5. MY CE-INNOVATION PROJECT**	Transversal Session dedicated to collaborative and critic skills		

Annex 2

Figure 4. Relationship between basic (B), general (G), transversal (T) and specific (S) skills and features of the CE-project considered to acquire them

SKILLS	How did the CE-Innovation Project contribute to acquire it?
B1. Students can apply the knowledge acquired and their ability to solve problems in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their field of study. S1. Adapt to structural changes in society caused by economic, energy or natural factors or phenomena in order to solve resulting problems and provide technological solutions with a high commitment to sustainability	The framework of the CE-Innovation Project was wide enough to cover all the technological fields a chemical engineer could be involved in, in a multidisciplinary view, combining knowledge from different disciplines. In particular, it was aligned with the current societal challenges of the European program of innovation in bioeconomy, which involves sustainability.
B2. Students are able to integrate knowledge and handle the complexity of formulating judgments based on information that, while being incomplete or limited, includes reflection on social and ethical responsibilities linked to the application of their knowledge and judgments. T1. Be able to access information tools in different areas of knowledge and use them properly.	The development of the CE-Innovation Project was based on a technological watching strategy that should be followed to cope with the necessary background to explain the technological innovation. In addition, one of the dimensions of the definition of the impact is the perspective of benefits for individuals, organizations and societies. As well, along the course, the students were taught different digital resources and online databases to prevent them from infoxication during the information search.
B3. Students have the learning skills that will allow them to continue studying in a way that will be largely self-directed or autonomous. T2. Be able to take responsibility for their own professional development and specialisation in one or more fields of study. T3. Have skills for independent learning in order to maintain and enhance the specific competences of chemical engineering, which enable continuous professional development. T4. Be able to assess the need to complete their technical, scientific, language, computer, literary, ethical, social and human education, and to organise their own learning with a high degree of autonomy.	The CE-Innovation Project itself, as tractor project, motivates the habit of learning by doing. As well, each session offers ways to extent the specialization of the students depending on their preferred roles. The flipped classroom permits self-paced learning and therefore to organize their own learning, helped with instant on-line feedback and posterior face-to-face feedback.
B4. Students have the knowledge and understanding that provide a basis or an opportunity for originality in developing and/or applying ideas, often within a research context. G1. Conduct proper research, undertake the design and lead the development of engineering solutions in new or unfamiliar environments by linking creativity, originality, innovation and technology transfer. G2. Adapt to changes and be able to apply new and advanced technologies and other relevant developments with initiative and entrepreneurship. S2. Manage research, development and technology innovation taking into account the transfer of technology and the property and patent rights.	The CE-Innovation Project was based on the result of the combination of creative generation and evaluation of ideas, which could be used to consider originality of innovations in different technologies. Innovation and technology transfers were the skeleton of the contents and framework of the development of the CE-Innovation Project. The entrepreneurship was promoted by the development of the CE-Innovation Project from the economic perspective, on the one hand, and on the competitive perspective, on the other hand.
G3. Communicate and discuss proposals and conclusions in specialised and non-specialised multilingual forums, in a clear and unambiguous manner. T5. Be able to defend criteria with rigor and arguments and to present them properly and accurately.	The CE-Innovation Project was defended at a public forum to different assessment boards composed by teachers, students and entrepreneurs.

Annex 3. Satisfaction questionnaire

Please, answer to the following affirmations according to the degree of agreement from 1 to 5, according to the following description:

1. Completely disagree
2. Partially disagree
3. Neither agree nor disagree
4. Partially agree
5. Completely agree

1. The utility of the learning platform used at the subject is appropriated.
2. The accessibility to the learning platform used at the subject is easy and fast.
3. The format of the digital resources at your disposal at the learning platform is appropriate.
4. The quality of the digital resources at your disposal at the learning platform is appropriated.
5. The utility of the digital resources at your disposal at the learning platform is appropriated.
6. The management of cooperation during teamwork is relevant.
7. The effectiveness of cooperation during teamwork is relevant.
8. Cooperation in teamwork improved the quality of your work.
9. Cooperation in teamwork improved your collaborative skills.
10. The pedagogical methodology (PBL+Flipped classroom) had and influence on my motivation.
11. The pedagogical methodology (PBL+Flipped classroom) had and influence on my participation.
12. The utility of project-based learning was relevant for the development of the subject.
13. The utility of flipped classroom was relevant for the development of the subject.
14. The methodology was relevant to move professional attitudes and perspectives.
15. I felt satisfied with the development of the subject.
16. I would recommend this teaching model to other subjects.