Learning-by-Doing: the Chem-E-Car Competition® in the University of Cantabria as case study

Antonio Dominguez-Ramos, Manuel Alvarez-Guerra, Guillermo Diaz-Sainz, Raquel Ibañez and Angel Irabien

University of Cantabria, Department of Chemical and Biomolecular Engineering,

ETSIIT, Avda. los Castros s.n., Santander, 39005, Spain

Corresponding author: Antonio Dominguez-Ramos

Tel.: +34 942 20 14 74.

Corresponding author e-mail: domingueza@unican.es

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ABSTRACT

It is widely known that the Learning-by-Doing (LbD) pedagogical tool is not the most common form of education in Chemical Engineering nowadays. The aim of this work is to describe the application of LbD considering as case of study the participation of undergraduate students from the Chemical Engineering Degree of the University of Cantabria (UC) from Spain in the Chem-E-Car Competition® in the 10th World Congress of Chemical Engineering (WCCE10). The Chem-E-Car Competition® is a world-known student event run by AIChE, which provides chemical engineering undergraduate students with the opportunity to participate in a team-oriented hands-on design and construction of a small prototype car powered by a chemical reaction. Within the context of the WCCE10, the competition gathered 18 teams from different countries all around the world. The UC team ended in the 6th position and won the award to the best inherent safety design. Overall, the benefits outpaced the time cost both for students and the teaching staff. This situation was not clear at the beginning of the project.

Prior to this competition, LbD was used as an innovative pedagogical tool for the requested acquisition of competences. The proposal of a multi-annual Final Degree Programme was a win-win situation for all the stakeholders. From a teaching point of view, the LbD let transferable and core competences to be evaluated not only internally, but also externally thanks to the competition. A survey was completed among the students that participated in the project. Competences such as "Problem-solving" and "Adaptation to new situations" were pointed out as those which were developed in a higher level by the students.

1. Introduction

Learning-by-Doing (LbD) is a pedagogical tool which constitutes an alternative to the widespread Learning-by-Repetition. This tool is not new and excellent teaching references as old as 30 years can be found, such as the open-access book from G. Gibbs (Gibbs, 1988). In fact, the idea of LbD is even older (which can be originally attributed to J. Dewey (Dewey, 1916)). As pointed out by R. Schank (Schank, 1995) at the time of his writing "…learning by doing isn't our normal form of education…". LbD is of great help, as it has "…the advantage of retaining the quintessence of traditional teaching qualities while rectifying its most recognized flaws" (Bot et al., 2005). Unfortunately, it is a shared belief that nowadays LbD is not the most common form of education in Chemical Engineering. The motivation for this can be twofold. Firstly, according to European ratios in terms of students per full-time professor(Times Higher Education, 2016), it seems difficult to fit this tool. The number of enrolled students can make extremely difficult to manage a workshop of such a size, consuming human and economic resources, being the later currently scarce in some countries such as Spain compared to others such as United Kingdom or Germany (The World Bank, 2018). Secondly, based on the authors experience as later shown, the preliminary cost-benefit analysis shows that a huge time investment is needed, with no future prospects of the return on investment.

A Chemical Engineer must have a resourceful background in "Doing Something Physical" (i.e.: something that can be "touched"), which is different in the cases of LbD in other disciplines (Ma et al., 2014). This essential skill implies the jump from the drawing board to a physical prototype, thus all cognitive domains of learning are considered (Anderson and Krathwohl, 2001). With a focus on the Chemical Engineering discipline, it is possible to quote Felder and Brent: "the only way a skill is developed … is practice"(Felder and Brent, 2003).Consequently, the LbD tool puts the practice or “Doing Something Physical” in the case of engineers in the very centre of the discussion.

A first pedagogical issue arises here, as the traditional approach seems to be failing at “Doing Something Physical”. Normally the degree courses are not oriented to create a prototype. A world-known example of LbD in the Chemical Engineering field is the Chem-E-Car Competition®(American Institution of Chemical Engineers, 2018)created by S. Fogler in 1998. The Chem-E-Car Competition® is oriented to undergraduate students. Under a regulatory framework, they must design, build and test a small-sized, inherently-safe and environmentally friendly car prototype powered by means of a chemical reaction, which has to cover a certain distance (unknown before the competition day) and then stop over a line. The role of the advisor/supervisor is merely on the safety of the car, so they cannot provide help at the development of the prototype. Previous works have described the Chem-E-Car experiences in several universities around the globe as a successful and positive teaching tool (Farhadi et al., 2009; Kamaruddin et al., 2012; Lewis et al., 2006; Lim and Moon, 2005; Rhodes, 2002). Moreover, related activities not included in the Chem-E-Car Competition® are also possible(Wang et al., 2013). In this sense, the follow-up question shows up: can the current Chemical Engineering teaching framework in Europe be aligned with this Chem-E-Car Competition® in terms of skills/learning outcomes?

The European Federation of Chemical Engineers published the document “Recommendations for Chemical Engineering Education in a Bologna Three Cycle Degree System” in 2010(European Federation of Chemical Engineering, 2010). In this document, among a set of competences/learning outcomes, it is stated that a first cycle degree chemical engineer must be able“…to develop a basic design for products and processes according to specified requirements”, “to use library and web resources for the acquisition of information regarding equipment characteristics and design methods, physical properties, kinetic and thermodynamic data"; "to demonstrate effective communication skills, both in writing and presentation, and to work effectively in teams"; and to have "understanding of applicable techniques and methods and their limits"; "the ability to organise and carry out projects"; and "an awareness of the non-technical implications of engineering practices". It is worthy to mention specifically those related to the transferable skills: "work individually and as team members in international and/or multidisciplinary teams"; "understand professional and ethical responsibility" and "learn on their own, and recognise the need for life-long learning".

The participation in the mentioned competition means that students must develop transferable competences in a high extension, such as team building, leadership and communication. In fact, these required competences/learning outcomes by the students are already listed in the official programme of the Chemical Engineering Degree in the UC(University of Cantabria, 2018). Those competences can be subjected to different extensions or levels (ranked from 1 –low level- to 3 –high level-). In general, the extension or level tends to be low in the transferable skills. For example, leadership is expected in some optative courses but in a low level1. Of course, not all the competences can be developed in its maximum level as was mentioned, since the degree has an equivalent workload of 240 ECTS (European Credit Transfer System).A summary is presented for selected transferable skills and core competences, comparing the level or extension in the Chemical Engineering degree and the Chem-E-Car® competition at UC in Table 1.The extension or level of development 1 is the lowest and 3 is the highest according to the UC score. The number of + represents a qualitative frequency of the demonstration of the selected competence. For example, the students perform tasks in pairs in the different courses, i.e. classroom problems, which correspond to a low level of teamwork (level 1). This is a very frequent activity (+++). However, having regular meetings, setting up monthly targets, etc. means a high level of teamwork (level 3)which is not needed in the degree (empty cell), but that is essential in the

Chem-E-Car competition®(+++).Several of the transferable skills/competences, such as the ability for autonomous work, are needed at their maximum level during the Final Degree Project (FDP), which has 12 ECTS. This project is mandatory for every single student enrolled in the degree. As later discussed, the possibility to bind the development of core and transferable competences requested by the FDP to the participation in the competition is a core element for the success of the proposal.

Of course, not only the transferable competences of a chemical engineer must be developed. It is evident that the core competences, as the nuclei of the degree, must be developed too. Some of them were previously mentioned in the EFCE recommendations. The students can perform properly in core competences in the levels 1 and 2, but the requested level for the core competences needed in the Chem-E-Car Competition® can be as high as level 3. Consequently, from a competences perspective, the participation in the competition means that core chemical engineering competences must be developed at its maximum level 3. The transferable competences in the Chem-E-Car Competition® must be developed at level 2 at least.

Table 1. Selected transferable and core competences and its corresponding extensions or levels of development.

Type	Competences	Extension or level of development					
		UC degree			Chem-E-Car Competition®		
		1	2	3	1	2	3
Core		++	++	+			+++
Transferable	Teamwork	+++	+				+++
	Leadership	+					+++
	Ability for autonomous work	+	+	+			++
	Capacity to apply knowledge to practice	+					+++
	Skills in interpersonal relations	+					+++

Another important point is the fact that the skills/learning outcomes are only internally validated through the extension of the degree. This means that, for example, the students must be able to communicate research results in front of the same cohort of professors during the four years, but never in front of an external committee (which is the normal situation in the academia or in the private professional sectors). An external evaluator judging the success of the learning outcomes is desirable.

The aim of this work is to describe the application of the Learning-by-Doing (LbD) pedagogical tool considering as case of study the participation of a group of undergraduate students from the Chemical Engineering Degree of the University of Cantabria (Spain) in the Chem-E-Car Competition® in the 10th World Congress of Chemical Engineering (WCCE10).The novelty of this work relies on being the first-time that this LbD pedagogical tool is applied in our Chemical Engineering Degree. The main barriers for the application of the LbD were identified and a worth-of-spreading solution to other universities is proposed. As a difference of previous works regarding the Chem-E-Car Competition®, a win-win solution for students (time-effective acquisition of core and transferable skills) and involved supervisors (academic recognition of innovative teaching activities) is envisaged. The assessment of the acquisition of competences was dually completed both at internal (FDP and a one-morning event with university representatives and the sponsor with the presence of regional news media) and external (Chem-E-Car Competition®, WCCE10) level. To measure the degree perceived by the students regarding the acquired transferable competences, a survey was performed. This was used to check if a reasonable progress towards the acquisition of competences was completed. On top of that, a cost-benefit analysis in terms of time-consumption regarding the application of the LbD methodology was completed. Main issues were clearly explained to support the exportation of the win-win proposed solution to other universities.

The materials & methods section describes the creation of the American Institution of Chemical Engineers (AIChE) chapter in the UC and the main characteristics of the case study. The results& discussion section provides details to allow the proposed win-win situation to be reproduced in other universities. This section starts with an initial cost-benefit analysis in terms of time-consumption both for the students and the professors (supervisors/advisors). The impact of the proposed tool was quantified in terms of the student perception about the developed competences. The survey performed is included at the end of the results & discussion section to check that the skills and competences have been properly acquired.

2. Materials & methods: Case study description

2.1. The Universidad de Cantabria Student Chapter

An AIChE Student Chapter is an official entity of AIChE made up of Student Members at any College or University with a Chemical Engineering Department. The Student Chapter Leadership Positions are held by AIChE Student Members at that University. The purpose of AIChE student chapters is to give Student Members the opportunity to develop project management skills and broaden their professional network by hosting educational events with AIChE.

The Universidad de Cantabria Student Chapter of AIChE was founded in 2011. At the time of the creation, this was the second chapter of AIChE in Europe. The team competing in the Chem-E-Car Competition® in 2017 was finally formed by a group of 3 female students and 4 male students. Since its creation two different supervisors have been leading the chapter. Two supervisors were involved in the initial stages of the project. The long-term goal of the chapter was the participation in the Chem-E-Car Competition® in the WCCE10.

2.2. Funding for the multi-annual programme

Having enough funding for the preliminary testing is essential. In this sense, it was the advisor of the chapter the one in charge of providing a sponsor for the initial testing. At the beginning of the multi-year programme, a local company, thanks to the willingness of its CEO, provided the initial funding for purchasing chemicals and testing prototype parts. Details of the company are provided in the acknowledgements section.

2.3. Brief description of the Chem-E-Car Competition®

Official rules established by the organization regulate the "Chem-E-Car performance competition" (American Institute of Chemical Engineers, 2017a).The main aim of the competition is to design and construct a car that is powered with a chemical energy source that will traverse a given distance carrying a certain additional load and stop, using a maximum time of 2 minutes. The required load and distance will be given to each team one hour prior to the start of the competition, which will be between 15 m and 30 m and between 0 mL and 500 mL of water, respectively. While carrying the specified load, the main goal of the competition is to stop the car closest to the specified finish line. Each car will be given two opportunities. The order of the teams in the first round of competition is determined by random drawing, and the order in the second one will be determined by the first-round standings, beginning with the team which finished farthest from the ending line. Since an objective of the competition is to demonstrate the ability to control a chemical reaction, the distance travelled, and the stop process must be controlled by a quantifiable change of the concentration of chemical species. No external devices are allowed to stop the car. Commercial batteries can only be used for specialized instrumentation (i.e. sensors or detectors), but their use is not permitted as the power source. Regarding the size of the vehicle, the only restriction is that all components of the car must fit into a box of dimensions no larger than 40 cm x 30 cm x 20 cm. The total cost of all these components of the box and the chemicals used must not exceed US$2,000.

2.4. Tasks prior to the competition day: Engineering Documentation Package (EDP) and poster

Before the UC team attended the event, the Chem-E-Car Competition® stipulates a set of mandatory and optional items. The mandatory items include an Engineering Documentation Package (EDP) and a poster presentation.

As stated in the Chem-E-Car Competition® Safety Rules (American Institute of Chemical Engineers, 2017a) “the safe preparation and operation of vehicles during all phases of the competition, including construction, testing and competition, is mandatory. There are 2 stages of the safety inspection, an online review where teams will submit an EDP electronically, as well as an on-site review on competition day”. Before the competition, all team members and the faculty advisor must complete the required safety training, which involve viewing two safety lectures coordinated by SaChE (Safety and Chemical Engineering Education) and the Chem-E-Car Competition® committee, and then taking, and passing, an online test (American Institute of Chemical Engineers, 2017b).

The EDP is a document that certifies the safety of the prototype. This document must include the procedure for the car to start-on and stop safely, hazards analysis, all the safety datasheets, all the individual protection items that will be used and the contingency methods in case of a malfunctioning. This EDP was submitted to a technical board of the competition one month in advance, so the teams can have enough time to modify their design to achieve safe conditions.

The poster presentation is a conventional normal-sized poster that must be focused in issues such as safety (is it safe?), novelty (why is different to other car prototypes?), cost (is within the budget?) and a technical description of the main elements.

The day before the competition the teams are scrutinized by a jury to check that the prototypes are safe (according to the EDP).

Additionally, teams can make a one-minute video presenting the team and the main features of the car, which is displayed during the competition. Each team is responsible for making the video.

2.5. Brief description of the Chem-E-Car of the University of Cantabria student Chapter

The first task carried out by the students was a literature review. The second one was to assess thoroughly different alternatives to decide the reactions involved in the two main mechanisms: movement and breaking. The first design to be prototyped was the result of the first two FDP. Safety was one of the key elements pursued during the design and building of the prototype. The last two FDP constituted the third final step, which resulted in the final building of the prototype.

The car is propelled by a stream of CO_2, which is the end product of the oxidation of sodium oxalate and potassium permanganate dissolved in water. The addition of a small amount of sulphuric acid provides heat and an acidic media. As a result, the pressure of the gas phase increases inside a tank. The pressurised gas acts over a piston. Several gears transferred the mechanical energy to the wheels. The amount of generated gas is enough to cover the maximum distance dictated by the competition.

For the breaking mechanism of the car, the iodine clock reaction was used. A small lamp lights a vial containing the solution. Behind the vial, a light detection resistance is located. An Arduino USB board was programmed to detect the change in the measured resistance due to the transition from transparent to dark blue colour. This transition acts over a relay, connected to an electrovalve, which is responsible for stopping the flow of gas to the piston. The time that passes between the addition of the iodate to the solution and the colour change depends on the concentration and on the temperature of the reactants.

2.6. Characteristic of the performed survey

As later described, while it was evident that there were competences that were demonstrated at a high level such as teamwork and leadership, it was necessary to quantify the perceived improvement. A survey was performed in order to get feedback on the perception of the students of the utility of the LbD project, with special emphasis on the development of transferable competences. A total of 12 anonymous surveys were received (92% of participation), with 50% of answers from male students and 50% from female students. Students involved in the project were surveyed in the first months of 2018. This set of students includes those that completed the FDP.

The surveys were anonymous and submitted in electronic form (no hand written). Students completed a survey in which the three main questions used for this work were:

1) Mark the competences that the Chem-E-Car® project has helped you to improve

2) What were the competences that you consider you have developed the most? Rank the top three competences among those provided.

3) The amount of time that you dedicated to the activity was much higher / higher / equal / less / much less than expected"

The list of competences (for questions 1 and 2) was provided in the same sheet to help the student at answering the questions.

3. Results and discussion

3.1. The Chem-E-Car Competition® in the WCCE10

Prior to the participation in the Chem-E-Car Competition®, the transferable competences were internally evaluated at the highest level (3). The level 3 means that the team of students must be able to report to the regional press media and describe a project in front of the public. To do so, a simulacrum of the real competition with only the UC team was organised. A similar simulacrum previous to the competition is typically organized before international events, in general, in the form of a classification (Kamaruddin et al., 2012). The students did show the proper performance of the car to the Dean of the University of Cantabria and the CEO of the sponsor company (please see the acknowledgements sections). The promotional one-minute video used in the day of the competition was broadcasted during the internal testing (see Figure 1 a) and b)). They completed several interviews in the regional media: press (see Figure 1 c)), TV and radio.

The day before the event (see Figure 1 d left)), the team passed the safety check and they defend their competition poster in front of an International jury. After two rounds (see Figure 1 e)), the UC Student Chapter ended in the 6^{th} position of 18 teams from Iran, China, USA, Canada, Poland, Qatar, and Spain. Even if the students did not finish in the top 3 places, they were really satisfied as the team received the “Best Inherent Safety in Design of Car” award (see Figure 1 d right)).

a) b) c)

EL DIARIO MONTAÑÉS

21/09/2017

De izquierda a derecha, los alumnos integrantes del grupo, Marián, Deva, Sergio, Carlos, Belén, José Manuel y Raúl.

Química para arrancar un coche

Alumnos de la UC diseñan un vehículo impulsado con dióxido de carbono

JOSÉ CARLOS ROJO

CADA DETALLE DEL INVENTO

d)

e)

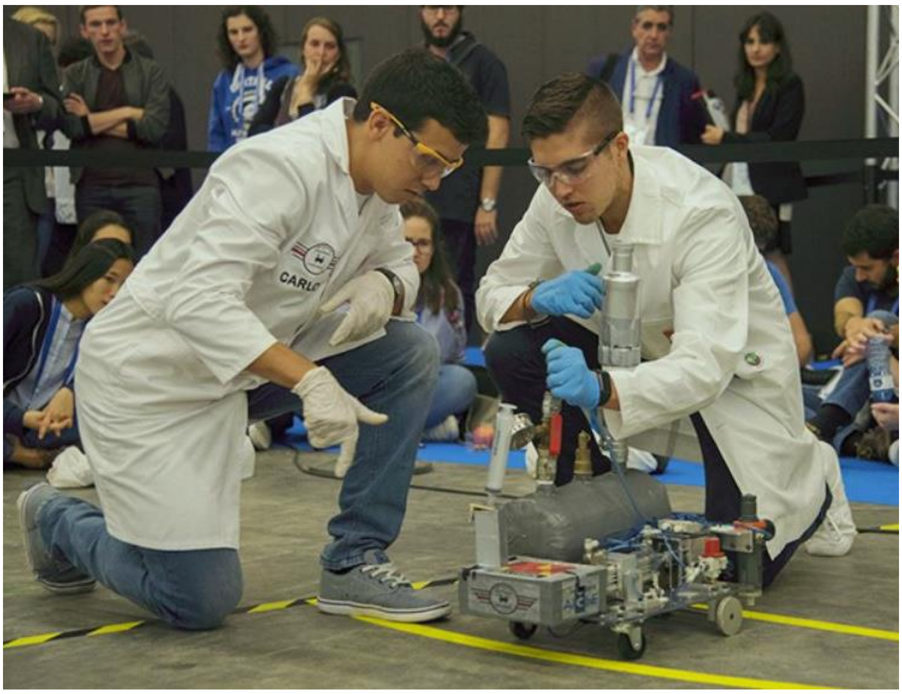

Figure 1. Selected captions from the promotional video and the reports in regional newspapers: a) and b) Two selected captions of the promotional video (https://www.youtube.com/watch?v=zmJSKUtCMNE); c) Regional press report; d) Team members during the poster presentation (left)and receiving the "Best Inherent Safety in Design of Car" award (right); e) Two students in the starting line the day of the competition;

3.2. Cost analysis for the students and the involved professors

At a first glance, it is evident that according to the previous results from the competition, the participation was paid off for all the stakeholders. Of course, this includes the experience of the WCCE10 as well as the design award.

However, these rewards were not foreseen right after the foundation of the student chapter. Firstly, it is of critical relevance to face the involved cost for the students. Mainly, the only available resource for the student is time. In fact, keeping in mind the ratio of 1.5 autonomous working hours per 1 hour at the classroom, it leads to a total of 30 hours of workload per week. As the ratio can vary widely, students carefully select the best utilization of the available hours, especially if they have to travel certain distances to university. The beginning of the LbD project showed a lack of student engagement, which in the authors' opinion was motivated by:

- The students participating in the WCCE10 were not the students at the time of assembling the team (2012). Of course, as they did not see themselves in the leading role of the project, a low initial motivation was observed.
- The potential lack of academic progress. The initial activities were not allocated to any existing course, thus no academic credits were going to be attached, and therefore the participation in the project was mainly driven by the individual interest of students of the UC student chapter.

The cost analysis of the involved teaching staff is also of interest. The most relevant issue in the staff' side was the transfer of time from mandatory activities (teaching and research project activities) to non-mandatory activities such as the one described in this work. Regarding this case of study, according to the professional university career in Spain, the progress from young researcher to associate professor is based on a national accreditation system. As the accreditation system is essentially based on the historical record of teaching hours of the individual and his/her number of published papers, devoting time to parallel project entails a certain risk, as potentially the submission can lack of enough quality (potential loss of his/her job). In fact, this is just another example of "publish or perish".

3.3. Proposal of solutions

According to the previous description of the cost for both the students and the involved teaching staff, the authors came up with a potential win-win situation. The solution relied on the development of a multi-annual FDPs Programme within the Chem-E-Car Competition® framework. This programme was designed to solve the initial issues detected at the beginning of the LbD project. The FDP (12 ECTS) is mandatory for all the students in the UC Chemical Engineering degree. Consequently, they do really need to complete a project which is granted with credits. This way the students realize the usefulness of participating in such a programme, as their work is rewarded. On the other hand, the involved professors are rewarded by an academic activity, which belongs to the mandatory activities and which, at the same time, is recognized by the national accreditation system. Consequently, both the students and the involved professors were rewarded. On top of that, the responsibility towards the sponsor made the students to be held accountable on the results of the competition. This was an extra driving force that additionally motivated the students participating in the competition.

The success of this multi-annual FDPs Programme is based on the defence of six FDPs during 2015, 2016 and 2017, with two projects per year. Figure2 summarizes the title, the year and the academic mark of the six defended projects:

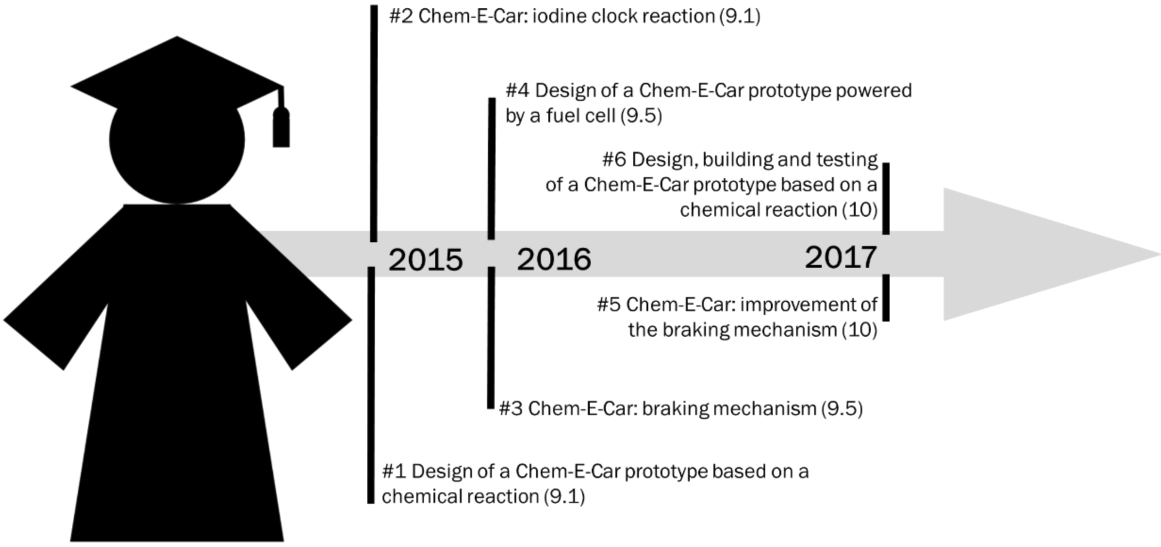

Figure 2. FDPs successfully defended in the multi-annual FDPs Programme. The corresponding mark in a scale 0-10 appears in brackets

As can be seen from Figure2, these projects were related so the information was based on the previous work. The general overview of the projects was designed in 2015 with the aim that in 2017 a prototype could be available for the competition. In the two first projects (2015), a preliminary design was drawn using the preliminary calculations from the students involved in the pre-multi-programme period. In the project #1, a preliminary design used AutoCAD to provide a rough initial design. Project #2 completed the experiments regarding the chosen iodine-clock reaction, giving as result a regression of the colour change time as a function of the reactants concentration and of the temperature. Project #3 designed the preliminary electric circuit responsible for the detection of the colour change in the iodine-clock reaction and the activation of an electrovalve. Project #5 improved the existing circuit and connected it to the prototype. Project #6 studied the permanganate-oxalate oxidation reaction and built the prototype. Project #4 performed a preliminary assessment of a different propulsion mechanism in case the permanganate-oxalate reaction could potentially fail. Of course, it is clear to the reader that only projects #3, #5 and #6 were projects in which “Doing something” was possible. As was mentioned, the poor initial engagement of the students made that a robust preliminary design was needed. This issue was solved in projects #1, #2 and #4. All the projects were highly marked (average value of 9.53 over 10) due to the quality of the reports and the oral defences. Consequently, core chemical engineering competences were internally assessed. The level of the core assessed competences was medium-to-high (2-3) for the six projects. These levels 2-3 mean detailed mass and energy balances, advanced knowledge of kinetics and chemical reaction engineering and the built of a prototype. Transferable competences were also assessed but the achieved level was low (1). The level 1 refers to the presentation in front of a committee composed of professors (which are all members of the degree). Of course, the students perform properly as it is not the first time they do that activity. The feasibility of the prototype was assessed in the FDPs. The projects #5 and #6 reported the behaviour of the prototype.

Table 2. List of competences and its internal/external assessment. E stands for Erasmus and/or European Project Semester

#	Competences	Internal		External	
		Degree	FDP	Demonstration at UC	Chem-E-Car Competition®
1	Capacity for analysis and synthesis.	✓	✓		
2	Capacity for organisation and planning.	✓	✓	✓	✓
3	Oral and written communication in one's own language	✓	✓	✓	
4	Knowledge of a foreign language	✓			✓
5	Knowledge of computer science in the field of study	✓			
6	Capacity for information management	✓	✓		
7	Problem-solving	✓	✓		✓
8	Decision-making	✓	✓		✓
9	Teamwork	✓		✓	✓
10	Working in an interdisciplinary team	E	E		
11	Working in an international context	E	E		✓
12	Skills in interpersonal relations	✓	✓	✓	✓
13	Capacity to communicate with experts in other fields	✓	✓	✓	
14	Recognition of diversity and multiculturalism	E	E		✓
15	Capacity for criticism and self-criticism		✓		
16	Ethical commitment		✓		✓
17	Capacity to apply knowledge to practice	✓			
18	Capacity for autonomous learning		✓		✓
19	Adaptation to new situations		✓		
20	Ability for autonomous work	✓	✓		
21	Creativity		✓	✓	✓
22	Leadership	✓			✓
23	Knowledge of other cultures and customs considering the interrelation with other students in an international environment	E	E		
24	Initiative and an enterprising spirit		✓		
25	Motivation for quality	✓			
26	Sensitivity towards environmental issues	✓	✓		
27	Ability for research		✓		
28	Project design and management		✓		

29	Motivation for achievement		✓		

3.4. Checking academic competences

The learning of academic competences can be assessed by a myriad of methodologies, going from oral exams to written reports or conventional tests. However, all these competences are assessed by the same teaching staff during the four years of the UC degree. Therefore, an external assessment of the competences is desirable to check how the students can performed in “the outside world”. Table 2 shows the list of transferable competences. A tick is used to highlight those competences evaluated internally and/or externally. The internal assessment is performed both in the courses of the UC degree and in the FDP. The external assessment took place during the internal demonstration of the prototype at the UC and the Chem-E-Car Competition®.

A graphical summary of the learning outcomes, the request organizational structure and the assessment strategies related to the described project is presented in figure 3. On an individual level, a student is subjected to a schedule in which he/she must reach certain learning outcomes to check the academic competences. Within the course, assessments are completed with no need of other students (unless a group project is discussed) and only one professor is needed in the whole process. This conventional situation which affects a large fraction of the courses anywhere is described in the top row from figure 3 considering one university. No teaching innovation exists here.

However, to “build something” the situation changes. This situation is described in the second from top row of figure 3 considering one university. As the individual learning is not enough, a team of students and the involved teaching staff must be assembled, as a single course cannot cover all the previous activities to the competition. This means that a more diverse set of learning outcomes are expected. The team of students, which are led by the students with direct responsibilities in the FDPs, have the capabilities to build and test the prototype. This situation is difficult to be conceived by a single individual, which seems rather obvious. Also, a team of professors (teaching staff) is needed to supervise the safety of the activities in the lab as well as for other issues that were needed to be solved such as finding a sponsor or guiding in the report of the project. Therefore this represents a new situation compared to the one previously presented: more than one student-professor pair is needed to apply the LbD methodology. The timeframe is also different. The conventional reach of a course is one semester (two semesters per academic year). The application of the LbD means a multi-annual framework, in which our initial estimation was of five years. The multi-year project idea did come up with after two years the project started. Thanks to this structure of teams, the competences can be evaluated at internal level (UC degree and FDP within the university), which proves that this internal structure was needed. In the previous section, the internal test (internal demonstration of the competition at the UC in front of the Dean and CEO of the sponsor company) was described and both transferable and core competences were evaluated.

However, the external assessment of transferable and core competences requested the participation of several universities under a supra-international instructional framework organization. This structure is needed to let the groups of students to compete between each other's in the Chem-E-Car Competition®. This situation is represented in the bottom row of figure 3 considering several universities.

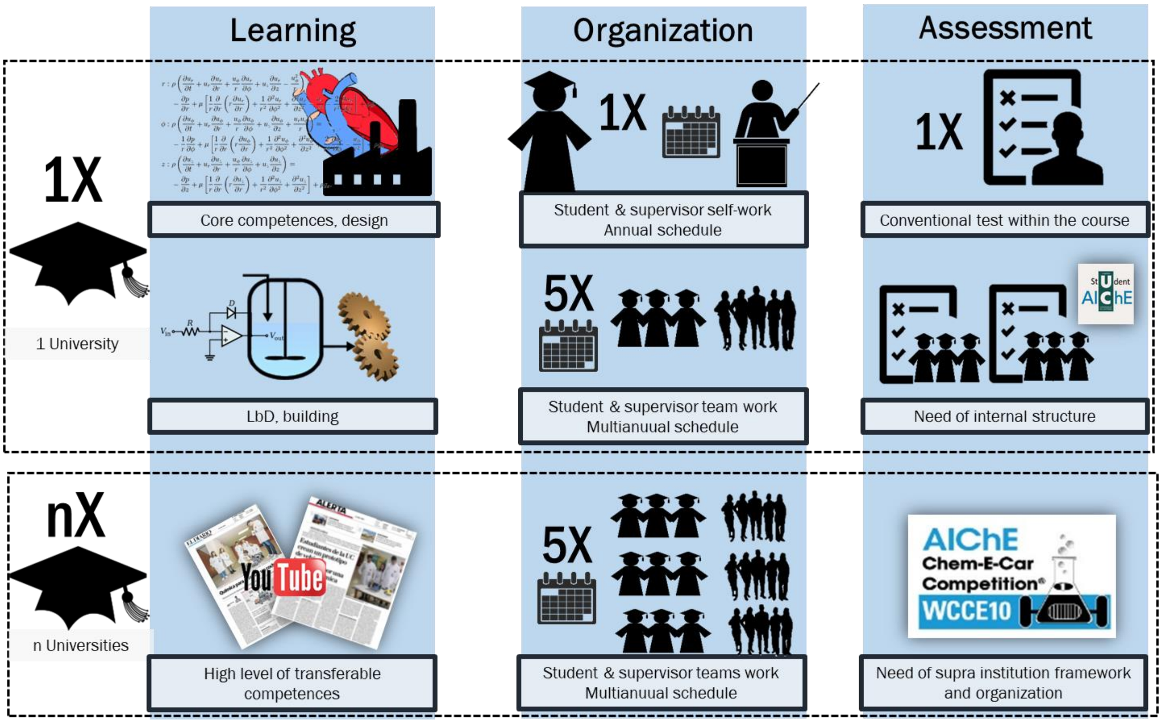

Figure 3. The need of a multi-university, multi-student and multi-teaching staff integration for the external assessment in the Chem-E-Car competition®.

3.5. Survey to students on their participation in the LbD activity

Figure 4 summarises the competences which, according to students' answers, their participation in the activity has helped to improve. Moreover, Table 3 lists the competences that the students ranked as those that they considered they had developed the most by being involved in the LbD project.

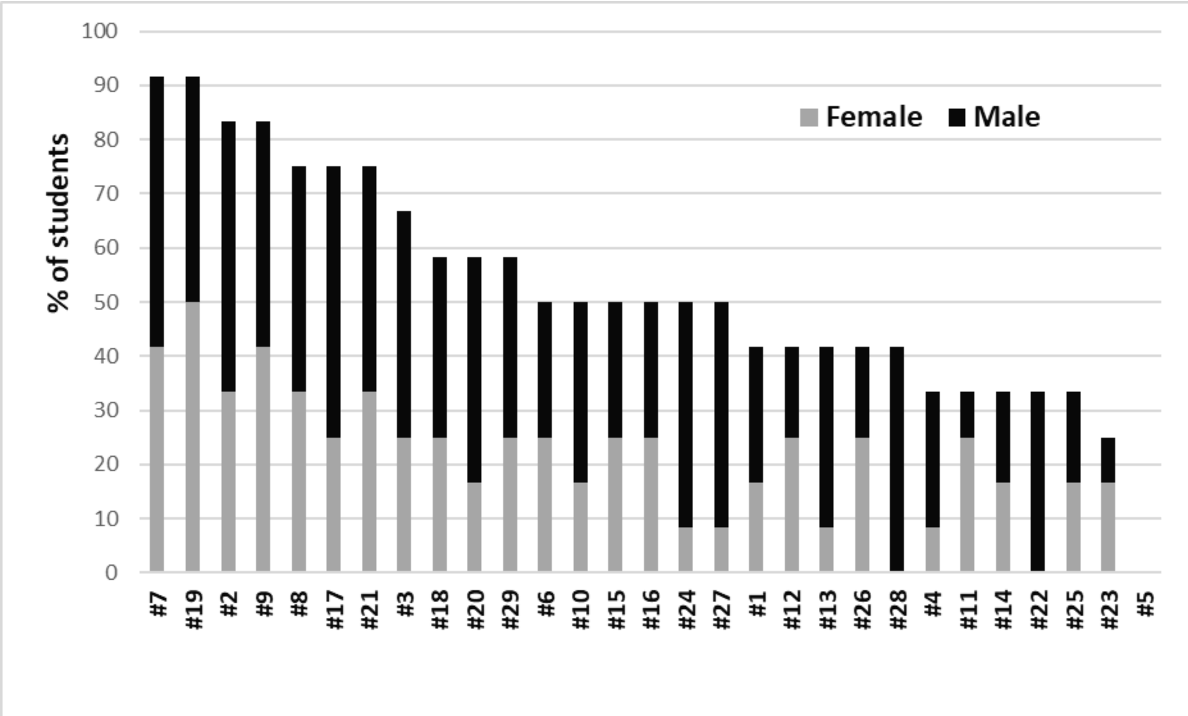

Figure 4. Results of the survey to students on the LbD project. Percentage of students that considered that their participation in the project was useful to develop each of these competences. Competence #7 was Problem-solving, #19 Adaptation to new situations, #2 Capacity for organisation and planning, #9 Teamwork, #8 Decision-making, #17 Capacity to apply knowledge to practice, #21 Creativity, #3 Oral and written communication in one's own language, #18 Capacity for autonomous learning, #20 Ability for autonomous work, #29 Motivation for achievement, #6 Capacity for information management, #10 Working in an interdisciplinary team, #15 Capacity for criticism and self-criticism, #16 Ethical commitment, #24 Initiative and an enterprising spirit, #27 Ability for research, #1 Capacity for analysis and synthesis, #12 Skills in interpersonal relations, #13 Capacity to communicate with experts in other fields, #26 Sensitivity towards environmental issues, #28 Project design and management, #4 Knowledge of a foreign language, #11 Working in an international context, #14 Recognition of diversity and multiculturalism, #22 Leadership, #25 Motivation for quality, #23 Knowledge of other cultures and customs considering the interrelation with other

students in an international environment, #5 Knowledge of computer science in the field of study.

Table 3. Results of the survey to students on the LbD project. Competences that the students ranked in the survey in the "Top 3" and as "Top1" of competences that they had developed the most by taking part in the LbD activity. Competence #7 was Problem-solving, #19 Adaptation to new situations, #2 Capacity for organisation and planning, #9 Teamwork, #8 Decision-making, #17 Capacity to apply knowledge to practice, #21 Creativity, #3 Oral and written communication in one's own language, #18 Capacity for autonomous learning, #20 Ability for autonomous work, #29 Motivation for achievement, #6 Capacity for information management, #10 Working in an interdisciplinary team, #15 Capacity for criticism and self-criticism, #16 Ethical commitment, #24 Initiative and an enterprising spirit, #27 Ability for research, #1 Capacity for analysis and synthesis, #12 Skills in interpersonal relations, #13 Capacity to communicate with experts in other fields, #26 Sensitivity towards environmental issues, #28 Project design and management, #4 Knowledge of a foreign language, #11 Working in an international context, #14 Recognition of diversity and multiculturalism, #22 Leadership, #25 Motivation for quality, #23 Knowledge of other cultures and customs considering the interrelation with other students in an international environment, #5 Knowledge of computer science in the field of study.

Competence	#19	#9	#17	#21	#2	#7	#15	#16	#18	#29	#1	#8	#20	#22	#23
% of students that ranked the competence in the "top 3"	50	42	25	25	17	17	17	17	17	17	8	8	8	8	8
% of students that ranked the competence as "top 1"	25	25	8	8	17	0	0	0	8	0	0	0	0	0	8

As shown in Figure 4, there are 17 of the 29 competences for which at least 50% of the students affirmed that the “Chem-E-Car” activity helped them to improve. Almost all the students (92%) felt that they developed the competences “Problem-solving” and “Adaptation to new situations”. Both, crucial competences for a chemical engineer, were also ranked in the “top 3“(Table 3). Particularly, “Adaptation to new situations” was in the top 3 for 50% of the students, and it was highlighted as the most developed competence by 25% of the 12 students. Other two important competences (i.e. “Capacity for organisation and planning” and “Teamwork”) were selected by 83% of the students, both also highly emphasised as most developed competence (17% and 25% of the students, respectively, Table 3). As shown in Figure 4, high percentages (75%) were received by “Decision-making”, “Capacity to apply knowledge to practice” and “Creativity”, which were also highly ranked in the “top 3” (Table 3). Therefore, it may be concluded that the results of the survey confirm the usefulness of LbD in helping students to develop key transferable competences in their degree of chemical engineering.

No significant differences were observed in the results of male and female students surveyed. The fact that competences like #24, #27, #13 or #28 (see Table 3), regarding initiative, ability for research or project design & management, received higher appreciation by male students could be explained because the students that carried out their FDP in the framework of this activity were mainly men (see Table 3). Apart from “#5: Knowledge of computer science in the field of study”, the competences that were least perceived by the students were those related with leadership, diversity, culturalism, knowledge of other cultures, working in an international context and knowledge of a foreign language (Figure 4). In future LbD projects, this perception may change if exchange students from foreign universities could be enrolled in the project together with students from the home university (e.g. like in the European Project Semester programme in the UC (Rivero et al., 2014)), forcing them to communicate in other language and to work in an international context.

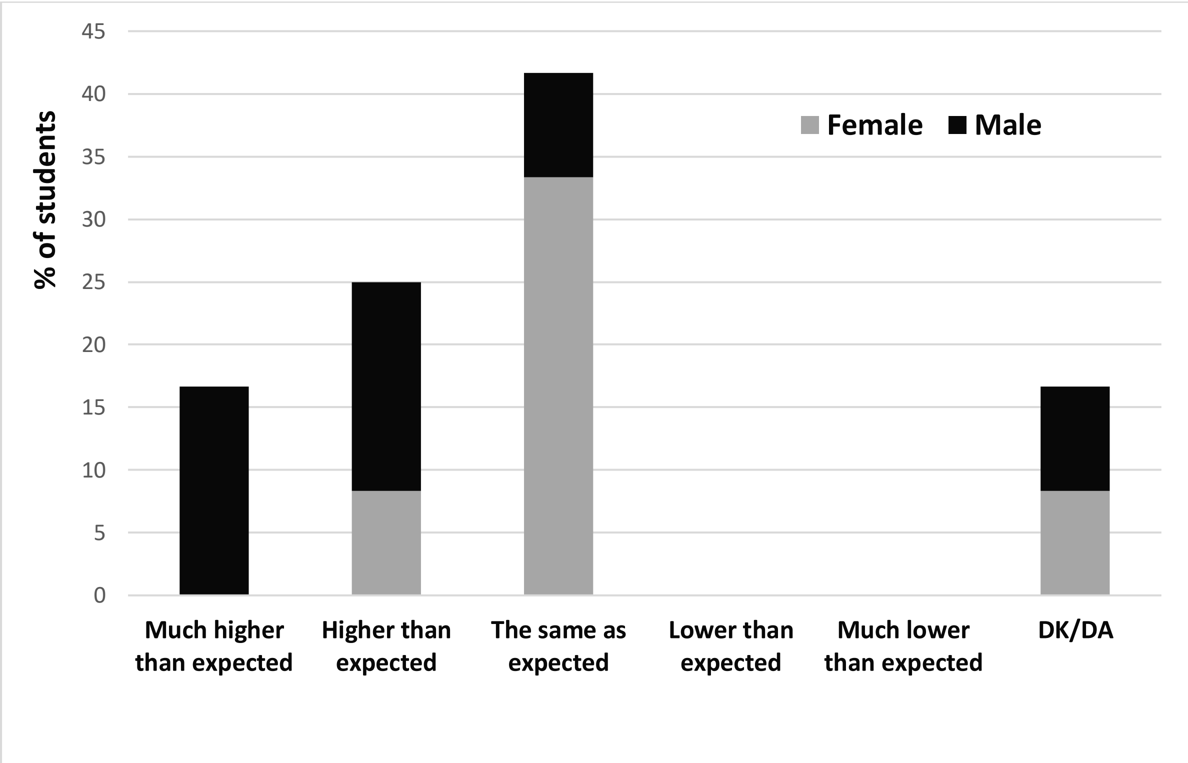

Figure 5. Results of the survey to students on the LbD project. Answer to the question: "The amount of time that you have dedicated to the activity has been…"

Finally, the students were asked to assess the amount of time they spent in the activity, compared to the amount they expected to spend before joining the LbD project. As shown in Figure 5, most of the students stated that the time they actually dedicated was the same as they expected when they got involved in the activity. Three students (25%) felt they spent more time than they expected beforehand, and for two students (16%), the amount of time was much higher than expected. It may be noted that most of the students that considered the time as "higher" or "much higher" were male, but again this could be attributed to the fact that most of the students that did their FDP in this activity were male. The results shown in

Figure 5 confirm the high time-consuming nature of the LbD activity. However, as pointed out when analysing the other results of the survey, the general perception of the students is that the LbD activity was a fruitful and gratifying experience that allowed them to develop in practice many key competences for a chemical engineer. As a summary, it can be stated that the cost in terms of effort was high but the rewards was also relevant, so the project was balanced in terms of the cost-benefit analysis from the student's perspective. In the professor's view, the win-win nature of the multi-year programme lead to a proper balance in the cost-benefit analysis.

4. Conclusions

Learning by Doing (LbD) is a pedagogical tool that helps at the development of chemical engineering competences. The regular schedule of chemical studies in undergraduate programmes in the Spanish University framework does not favour the use of such tools. The participation of undergraduate students from the Chemical Engineering Degree of the University of Cantabria (UC) in the Chem-E-Car Competition® held in the 10th World Congress of Chemical Engineering (WCCE10) has been used as a pilot program to introduce the LbD tool in these studies and as a case study to evaluate its contribution to the acquisition of desired competences in chemical engineering students. Those competences are evaluated both internally (University of Cantabria) and externally (Chem-E-Car Competition® at the WCCE10). The initial barriers detected (lack of initial student's engagement) were solved by a multi-annual Final Degree Project Programme, which ended up being a win-win situation for both students and involved professors. Driving forces, such as the existence of an international competition and the trust of the sponsor company, were critical for the success.

Improving the level of transferable competences of the students was a reality according to the completed surveys among the participants in the project. Competences such as "Problem-solving" and "Adaptation to new situations" were highlighted as those which were developed in a higher extension or level.

In general, it can be stated that the benefits compensated the costs per a large margin according to the results discussed in this work, thus this LbD pedagogical tool is recommended to be extended. This did hold true for both the students and the professors involved. Once the Chem-E-Car Competition® as driving force has ended, a new one must be pursued. The authors recommend the celebration of national Chem-E-Car competitions and the possibility to create a European oriented competition based on the urging problems and features of this world region such as Sustainable Production and Consumption in the context of a Circular-Low Carbon Economy.

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