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Reprint of: Education of chemical engineering in Spain: A global picture☆

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ABSTRACT

The general framework of the Chemical Engineering studies in Spain includes the Bachelor's Degree (4 years), Master's Degree (the most common duration is 1.5 years) and Doctorate (3-4 years). In 2008, the Conference of Directors and Deans of Chemical Engineering (CODDIQ) was constituted with the main objective of promoting and improving the quality of Chemical Engineering studies in Spain. Currently, Faculties and Schools of 29 Spanish universities are members of CODDIQ. An analysis of the most characteristic indicators provides a representative radiography of the Chemical Engineering Studies in Spain, whose most outstanding data are: (i) 7,396 undergraduate students, 1,014 Master students and 556 PhD students, (ii) according to the gender profile of undergraduates and graduates, the percentage of women is similar to that of men, while for faculty staff, the percentage of women is 43% and 46% for Associate and Assistant Professor (respectively) and 23% for the category of Full Professor category; (iii) after completing the Bachelor studies, most of them continue their training in the MSc in Chemical Engineering, (iv) the employability after obtaining the Master's degree is very high (>75%), which in the case of PhDs is close to 100%. The studies of Chemical Engineering in Spain have a very direct relationship with society, especially in the chemical, environmental, biotechnological and energy fields. The companies that collaborate in the training of future professionals are distributed throughout the national territory, which allows a strong connection with the socioeconomic environment.

1. Framework of chemical engineering studies in Spain

The implementation of the European Higher Education Area (EHEA, 2016) following the Bologna Declaration meant the transformation of the Chemical Engineering studies in Spain. At the beginning of this decade, new degrees were launched, covering the different levels of qualification: Bachelor, Master and PhD. The Bachelor in Chemical Engineering, like all other engineering degrees, has a duration of 4 years (240 ECTS - European Credit Transfer and Accumulation System; 1 ECTS implies 25 h. of work for the student). The curricula of practically all Bachelor studies follow the guidelines necessary for obtaining the professional degree in the field of engineering, in accordance with the professional duties contained in the Order of the Ministry of Science and Innovation (Orden CIN/351/2009). In relation to the Master, the duration of the studies depends on the university and ranges between 60 and 120 ECTS, although the most common value is 1.5 years (90 ECTS). The Master study programmes follow the guidelines (competencies and recommendations) published in the Resolution of 8 June 2009, issued by the General Secretariat of Universities, in which the Agreement of the Council of Universities on official university degrees linked to the practice of the profession of Chemical Engi-

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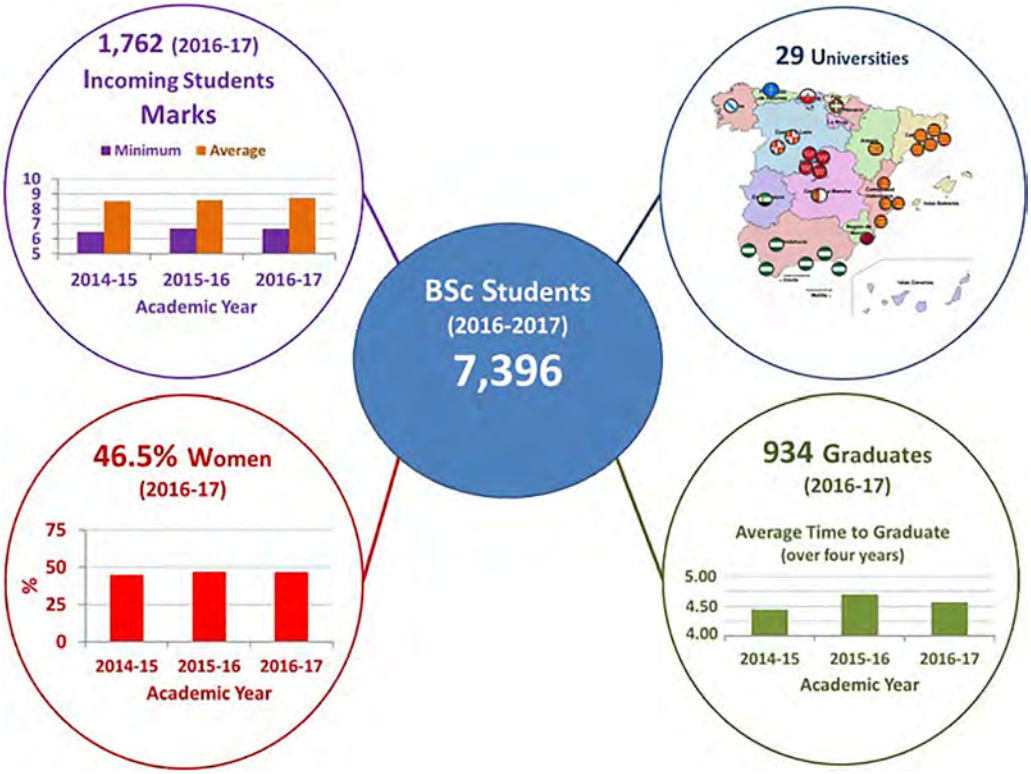

Fig. 1. Profile of students who study BSc in Chemical Engineering in Faculties and Schools members of CODDIQ. The data includes: (i) total number of students enrolled in the degree; (ii) number of students enrolled in the first academic year; (iii) distribution by gender and (iv) graduation rate.

neer is announced (BOE, 2009). The duration of doctoral studies in Spain is scheduled for 3 years (full-time), from the admission of the doctoral candidate to the program to the presentation of the doctoral thesis, but the current value in Chemical Engineering is between 3 and 4 years. The Doctorate studies end with the preparation and defence of a doctoral thesis that incorporates the original results of the research. The doctoral studies are organized through programs in accordance with the criteria established in Royal Decree 29/2011 (BOE, 2011).

The Conference of Directors and Deans of Chemical Engineering (CODDIQ, www.coddiq.es) was created on 12 May 2008 with the aim of meeting a number of objectives, ranging from the promotion of the constant improvement of the quality and image of Chemical Engineering studies to the formulation of proposals related to the teaching of Chemical Engineering at different educational levels and, in particular, on general guidelines for curricula and their integration into the European framework for Higher Education. Beyond teaching activities, scientific activity in the various fields of Chemical Engineering should be promoted, in connection with other scientific and technical areas and with companies and entities, with the aim of promoting research in the university and non-university fields.

At present, Faculties and Schools from 29 Spanish universities are members of CODDIQ, involving around 85% of all Spanish universities that teach Chemical Engineering, with a representative geographical distribution (Fig. 1). CODDIQ is an open association; its members must: (i) teach at the Bachelor and/or Master level in Chemical Engineering; (ii) comply with the statutes of the association; (iii) pay an annual fee. The Professional Institutes of Chemical Engineering in Spain also belong to CODDIQ: COEQGa (Galicia, www.coeqga.es/web/index.php), COIQCV (Comunidad Valenciana, http://www.coiqcv.com/) and COPIQCLM (Castilla-La Mancha, https://copiqclm.com/). One of the CODDIQ flagships is the holding of a biannual Conference on Teaching Innovation in Chemical Engineering (http://www.coddiq.es/cidiq/), of which four editions have already been held: 2012 Granada, 2014 Valencia, 2016 Alicante and 2018 Santander. The most relevant data from the last edition were: (i) 145 participants from 28 Spanish, one Peruvian and one British universities; (ii) 53 oral presentations; (iii) 82 poster presentations.

2. Bachelor in chemical engineering

Chemical engineers have technical knowledge of chemistry, biochemistry, engineering, materials science and information technology. However, they also know about economics, management, safety and environmental protection. The tools they have access in the laboratories include sophisticated scientific experiments, the latest developments in computing and large-scale pilot plants. Beyond the achievement of the fundamentals and methods in Chemical Engineering, the Bachelor aims to accomplish the development of transversal and non-technical skills, including ethics, responsibility and safety issues. In this context, graduates are able to design specified machines, equipment and processes, understand and apply design methods, use literature research from various sources, plan and conduct experiments on their own, communicate efficiently in oral and written form with colleagues, collaborative work in teams including international members and organize their work and time schedules, among other capabilities. One of the highlights in the Bachelor programme is the Design project, conceived as an individual or team work, in which students plan a production plant from scratch, including plant layout, environmental and safety analysis, as well as the calculation of costs and the economic viability of the project. In a few cases, however, students undertake a work based on an original research within the framework of a university laboratory or research group. The final exam is a final presentation at Faculty with analysis and discussion with the Evaluation Committee.

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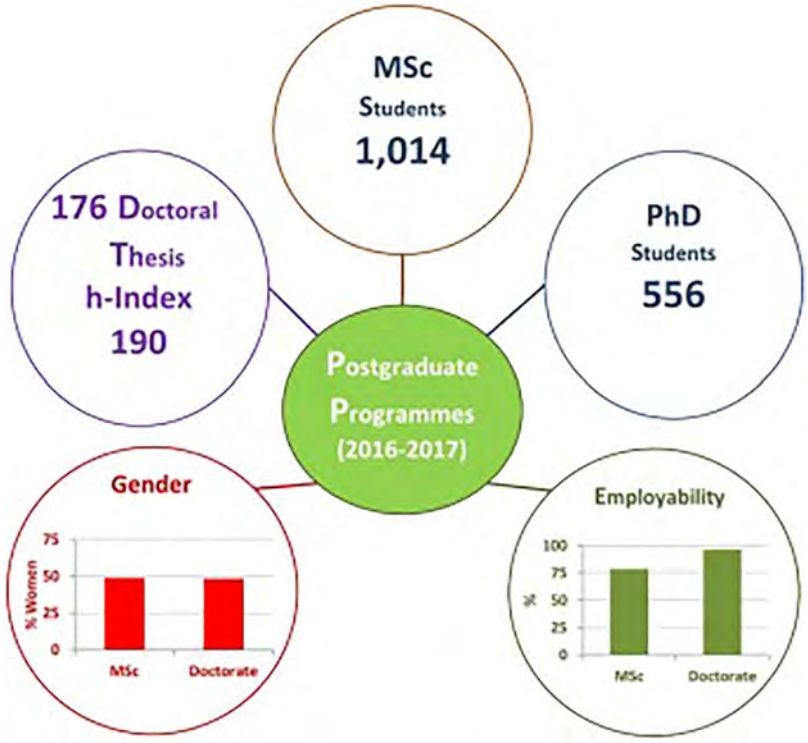

Fig. 2. Main data of the graduate programmes: Master and Doctorate.

In the 2016-2017 academic year, 1,762 students began their studies in the Bachelor in Chemical Engineering at the 29 member universities of CODDIQ (Fig. 1). Spanish universities define a certain number of places in each degree, and admission is defined according on the basis of the best scores obtained in the exams required for the access to University studies. In Spain, two indicators are usually considered to assess the demand for university degrees: (i) entry grade, which represents the minimum entry mark (the student in the last place establishes the cut-off score for admission), and (ii) average grade, calculated for the students who enrol for the first academic year. The demand for Chemical Engineering studies is high (https://www.educacion.gob.es/notasdecorte/), with a minimum access score of over 6.8 and an average grade of 8.8 These values place it among the engineering degrees with the highest demand, together those of Aerospace and Aeronautical Engineering, Electronic Engineering and Mechanical Engineering.

One of the most significant aspects that characterizes the Chemical Engineering studies in Spain is the gender profile, since parity is practically achieved (46.5% of women). These values are clearly higher than the average percentages reported for the different engineering degrees in Spain, with a value between 20-30%. At European level, the percentage of women graduates in Engineering maintains the same trend as in Spain, with average values of 27% (data published by Eurostat in July 2017: http://ec.europa.eu/eurostat/web/products-eurostat-news/).

In the Spanish university system there are different indicators for monitoring learning outcomes. One of the indicators is the average time to graduate, which is defined as the average time (in years) needed to pass all the credits in the curriculum. This value provides information on the degree of efficiency of the students and the institution in relation to the academic activity. Therefore, the optimal value of this indicator would correspond to 4 years, which is the period for which the curriculum has been designed. The average value of this indicator for Chemical Engineering studies in Spain over the last three years is around 4.5 years. This value is in the lower range for the duration of engineering degrees, which normally range from 4.5 to 5 years.

Becoming a Registered Chemical Engineer is considered by many to be a benchmark of excellence within the profession, as the Registered Engineer must meet specific criteria in terms of academic qualifications, work experience and commitment to professional development. The Bachelor and Master degrees of Spanish universities are evaluated periodically (in relation to the overall performance and assessment of learning outcomes) by the National Agency for Quality Assessment and Accreditation (ANECA, Spanish acronym: http://www.aneca.es/), or their counterparts in the different Autonomous Communities (administrative bodies into which the Spanish state is divided). ANECA is part of The European Quality Assurance Register for Higher Education (EQAR: https://www.eqar.eu/). In addition, the external evaluation coordinated by The European Association of Quality Assurance in Higher Education (ENQA: http://www.enqa.eu/) has determined that ANECA meets the Quality Assurance Criteria for the European Higher Education Area.

With the aim of internationally accrediting chemical engineering studies in Spain, CODDIQ promotes and recommends among its partners the implementation of appropriate actions to achieve this internationalization. The international accreditations held by the BSc in Chemical Engineering are: IChemE (Univ. of Oviedo and Univ. of Santiago de Compostela; www.icheme.org), ABET (IQS School of Engineering; www.abet.org/), EUR-ACE® (Univ. of Alicante, Univ. Jaume I de Castellón, Univ. Politécnica de Madrid, Univ. Politécnica de Valencia, Univ. Rovira i Virgili; www.enaee.eu/).

3. Master and Doctorate Programmes in Chemical Engineering

Connecting with the above, it should be noted that international accreditation for Master's studies is currently under way. So far, only two universities have international accreditation for the MSc in Chemical Engineering: Univ. Rovira i Virgili (EUR-ACE®) and Univ. of Santiago de Compostela (IChemE). The number of students enrolled in the 2016-2017 academic year is 1,014 in Master and 556 in the doctoral programmes of the CODDIQ Universities (Fig. 2).

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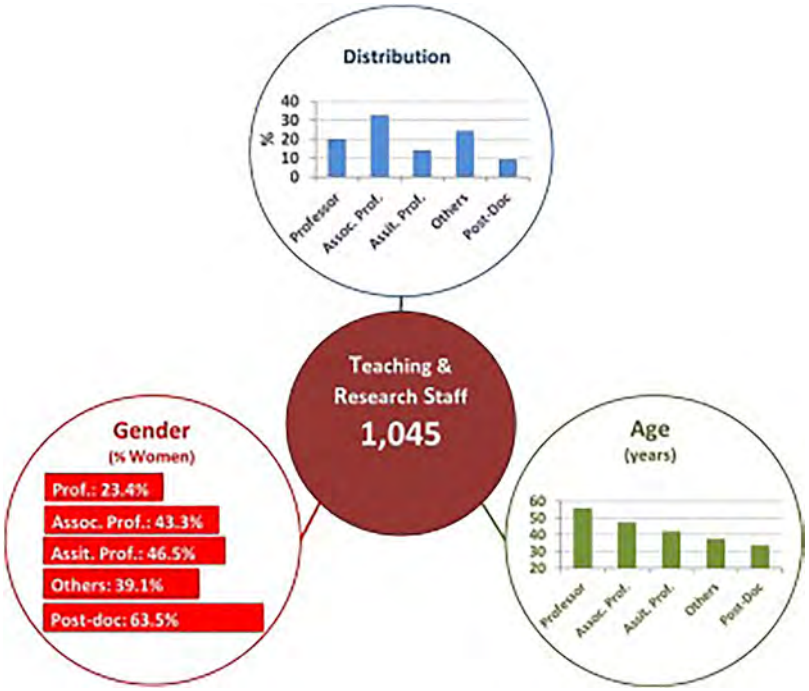

Fig. 3. Distribution by category, age and gender of Chemical Engineering faculty staff.

In the 2016-2017 academic year, a total of 176 doctoral theses were defended in CODDIQ Universities. A simple bibliometric analysis carried out with the Scopus database (www.scopus.com) where two terms were introduced in the search engine: "Chemical Engineering" and "Spain" reported an index h of 190 (calculated on 14/02/2018), which places the field of Chemical Engineering with one of the highest h indexes among the Engineering disciplines in Spain.

The gender profile of students in both Master and Doctoral programs maintains the trend for undergraduates, with parity at values of 48.8% and 48.2% for women, respectively. The employability of Master and PhD graduates is very high, with values close to full employment after completing their studies.

4. Teaching and Research Staff

There are several categories of teaching staff in Spanish universities, three of which are permanent: Assistant, Associate and Full Professor; the last two are civil servants. The distribution and age of the different categories of Chemical Engineering faculty (Fig. 3) is very similar in relation to the overall data for Spanish university faculty (MECD, 2015). The average age for permanent contract stability is over 40, making it extremely difficult to recruit and renew staff. Another important fact to be taken into account is the lack of mobility of teaching staff in the Spanish university system, in which practically the majority of professors reach their professional stability in the university where they completed their doctorate. The main data for the Faculty staff of Chemical Engineering (CODDIQ members) are: Professor (20.0% and 55.5 years), Associate (32.5% and 47.2 years), Assistant (14.0% and 41.7 years).

One of the aspects in which Chemical Engineering stands out positively in the Spanish scenario is in the distribution of the gender profile, since the percentage of women is in the average or slightly higher value [ChemEng/Global Spain]: Professors [23.4%/20.9%]; Associate Professors [43.3%/39.9%] and Assistant Professors [46.5%/44.3%] (MSSSI, 2018). If these percentages are compared with other engineering disciplines, the percentage of women in the various categories is significantly higher than the average; for example, 23.4% of Chemical Engineering Professors are women, compared with only 8% in all engineering disciplines (MINECO, 2015).

5. Chemical Engineering vs. Society

Most undergraduate and master degree programs obligatorily include internships in companies during the training period. The standard duration of an industrial internship for undergraduate studies is 12 weeks, whereas the value in the Master is about 16 weeks. In relation to the type of company in which the students carry out their internships, two fundamental groups have been considered: (i) R&D Centres (i.e. university research groups) and (ii) Industry. The latter group has been subdivided into the following industrial sectors: Biotechnology, Chemistry, Energy and Environment. The remaining options for the industrial sector have been considered under the heading 'Others'.

Fig. 4 shows the distribution of the companies (including the type and type of activity) in which undergraduate and graduate students carried out internships during the 2016-2017 academic year. A total of 817 students (515 undergraduates and 302 graduates) participated in the internships (Fig. 5). As the results show, no significant differences were observed between both groups with the same trend.

The procedure for the selection of the company in which the internship is carried out is mainly carried out according to two mechanisms: (1) the student seeks the internship in the company by himself/herself, or (2) the Schools propose a unified offer and internships are assigned to students according to their preferences and curriculum. In both cases, the companies in which the internships are carried out are mainly located in the geographical area of influence of the universities, which in the case of Spain corresponds to the administrative division into Autonomous Communities (whose dividing lines are indicated on the map). It should also be noted that, in most cases, internships in companies are not remunerated.

The students mainly choose to carry out internships in the industrial sector (85.1%), with a profile very similar to that of

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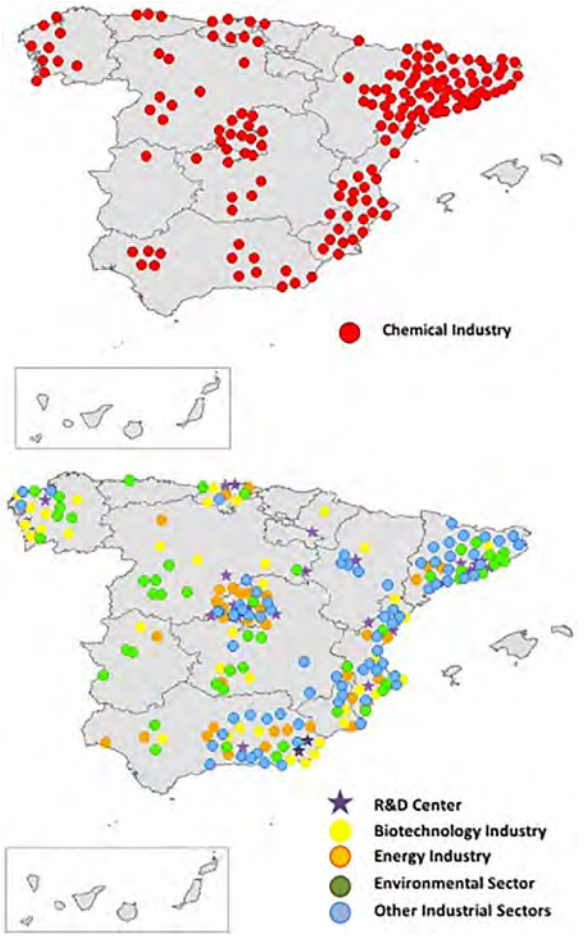

Fig. 4. Geographical distribution in Spain of the companies participating in the internship programmes of BSc and MSc in Chemical Engineering.

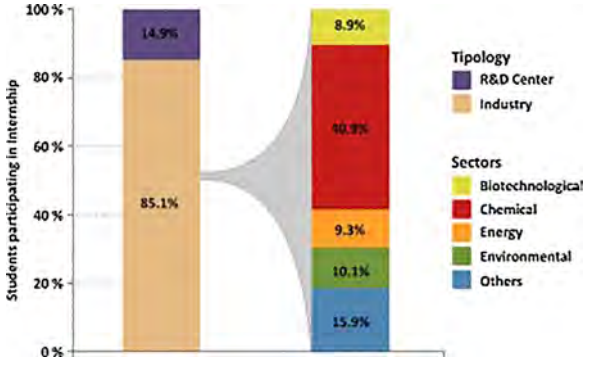

Fig. 5. Profile of industrial sectors selected by the students.

the sectors of greatest interest to Chemical Engineers worldwide (in decreasing order of interest): chemical industry (40.9%), environmental sector companies (10.0%, with special emphasis on companies dedicated to wastewater treatment), energy industry (9.3%) and biotechnology industry (8.9%). The heading "Others" includes a miscellany of sectors, e. g. nanotechnology, electronics and computing, business and consultancy.

Most of the degrees have an External Advisory Committee with several stakeholders, mainly the companies that collaborate in the internship programs, which turn to be the major employers of the graduates. These committees have suggested the short-term challenges to be addressed in the training of Spanish Chemical Engineers focusing on Sustainability, Circular Economy, Resilience,

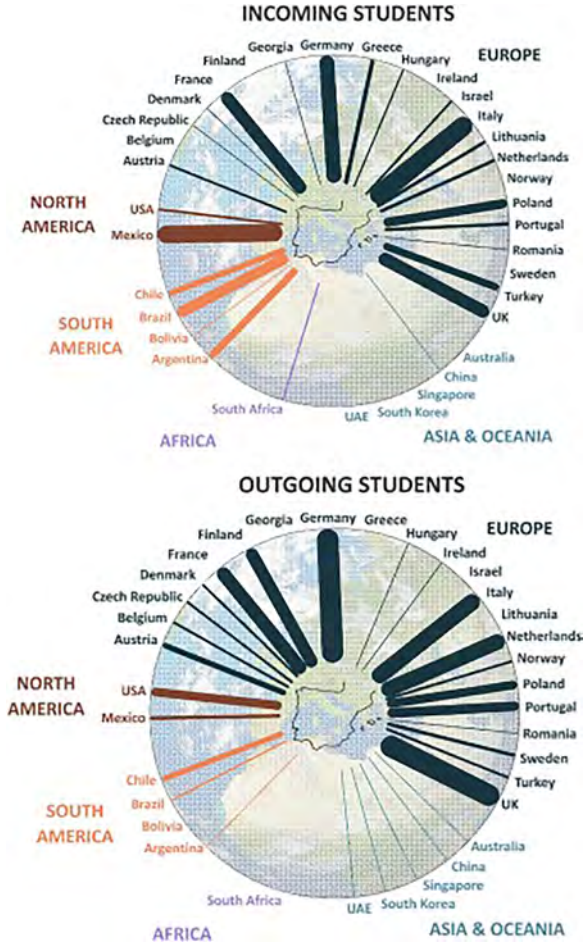

Fig. 6. Countries where student exchanges took place during the 2016-17 academic year.

Communication Capacity and Information Management in a Big Data society.

6. International student mobility

One of the aspects of special interest in the Bachelor and Master studies in Chemical Engineering is the promotion of international student mobility. In the 2016-2017 academic year, the number of incoming and outgoing students was 241 and 234, respectively (Fig. 6). Among the different international mobility programmes, "ERAMUS" and "Bilateral Agreement" present the highest numbers of mobility indices.

The Erasmus Programme (European Region Action Scheme for the Mobility of University Students) is a European Union student exchange program created in 1987 (https://ec.europa.eu/programmes/erasmus-plus/node_en). Students join the Erasmus Programme to study or do an internship for a period of at least 3 months to one academic year in a host institution of another European country. The Erasmus Programme guarantees that the period of stay abroad is recognised by their home university upon their return, provided that the previously agreed terms are met. This programme is the one with the highest flow of students (Fig. 6), with 77.5% of the exchanges.

The "Bilateral Agreement" mobility programme aims to facilitate exchanges with universities outside the European Higher Education Area. For cultural reasons, exchanges with Latin American universities represent the major percentage (16.8% of the total), but the number of foreign universities participating is very large.

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Although this type of agreement also guarantees the recognition of studies in terms of ECTS credits, the costs incurred by students in this programme are higher than those of the ERASMUS programme, as this programme only guarantees that students do not pay fees at the host university and does not provide any financial support for travel or accommodation.

7. Future perspectives

The challenges defined by the CODDIQ for the coming years will be developed in different areas of action: (i) international projection and accreditation of chemical engineering studies in Spain, (ii) collaboration with Professional Associations so that the profession of Chemical Engineer can be qualified as "regulated" in Spain; (iii) systematic monitoring of quality indicators related to chemical engineering at the Spanish level; (iv) creation of a video library in Spanish with aspects related to teaching activities in Chemical Engineering. Additionally, one of the most important strategic actions is the organization of the Congress on Teaching Innovation in Chemical Engineering, considered a reference for the exchange of teaching experiences in different fields of Chemical Engineering, acting as a networking and tutorial forum for new generations of teachers.

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