PROCESS SAFETY TRAINING FOR CHEMICAL ENGINEERS IN SPAIN: OVERVIEW AND THE EXAMPLE OF THE POLYTECHNIC UNIVERSITY OF VALENCIA

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Abstract

The dramatic growth of the chemical industry in the last century showed its great impact on the development of society but also its danger to humans and the environment, especially by the severe accidents at Seveso or Bhopal. As a result, public concern and perception of the impact and effect of these large installations on the safety of people and their environment led to changes in the chemical industry but also in Chemical Engineering as a discipline and profession. In the last 40 years, safety training has been introduced into the university curriculum of these professionals, especially promoted by accreditation agencies. This paper analyzes the curricular and methodological approach of the introduction of this discipline in the curriculum of Chemical Engineers and illustrates the current situation with the analysis of the curricula in the Spanish universities. Finally, it describes the implementation of this subject with the use of active methodologies in the case of the teaching of "Industrial safety" for Chemical Engineering degree students at the Universitat Politècnica de València (UPV). Results from assessment performed show benefits of the activities and methodologies developed to improve the level of learning and acquisition of professional competences of the safety-attending students.

Keywords: Safety education, chemical engineer, curriculum, training

1. Introduction

1.1 Teaching safety in the field of chemical engineering: origin and development

Safety and health is a concept that has been known for centuries, however, its true meaning arises from the industrial revolution, where there was a considerable increase in industries and also in the number of serious accidents that occurred in these, without the same progress in techniques to avoid them. It was in the 19th century, and thanks to the pressure of public opinion, that the first initiative to improve this situation arose, through a decree published in 1813 in France related to accident prevention (Wybo and Van Wassenhove, 2016). Other actions of that period established the first effective safety measures such as factory inspections (following the "Factories Law" published in England in 1833) (Swuste et al., 2010), the creation of occupational accident statistics offices or the mandatory use of hazardous machinery guards in the United States, which were later extended to other countries. Especially relevant was the creation of the American Society of Safety Engineers (ASSE), in 1911, and the International Labour Organization (ILO) in 1918, with its division on Safety and Accident Prevention, which laid the foundations for the prevention and protection of workers against diseases and accidents resulting from work and for training and information on this matter.

Over the years, the concept of industrial safety (Werther and Davis, 1995) has evolved from the consideration that occupational accidents were due to dangerous physical and mechanical conditions to the consideration that the human factor was essential in reducing occupational accidents to a minimum, focusing on improvements in worker education as a tool for minimizing accidents (Heinrich, 1931).

This concept has favored the incorporation of safety training in the work and university environment, and especially in the formation of engineers (Heinrich, 1956; Swuste et al., 2010), being the universities of the United States (Talty, 1986), Netherlands (Lemkowitz, 1992) and Australia (Woolley and Viner, 1980) the pioneers in the integration of safety issues in engineering studies.

In the case of Chemical Engineering, the concept of Safety & Health and prevention of occupational hazards takes on special importance. The chemical industry, with its dramatic growth, especially in the 19th and 20th centuries, has made clear its great impact on the development of society but also its danger to human beings and the environment, especially due to the serious accidents that have occurred in some of them. Accidents such as that of Flixborough in 1974, Seveso in 1976, or Bhopal in 1984 (Willey et al., 2005), are some examples. As a result, public concern and perception of the impact and effect of these large facilities on the safety of people and their environment led to changes in the chemical industry but also in Chemical Engineering as a discipline and profession. The academic response to public concern

about health and the environment following these accidents was immediate, urging universities to train engineers experts in industrial safety (Perrin and Laurent, 2008).
In the case of chemical engineering, there is a common agreement that this discipline should be mandatory in all courses (Pitt, 2012; Shallcross, 2013), as a tool to prevent accidents, because chemical engineers:
-Have a relevant role in preventing and reducing the risk associated with accidents that may occur in a plant or industrial activity, and propose preventing measures against hazards in the production process (Amaya-Gómez et al., 2019; Darbra et al., 2012).
-Will be responsible for the future design and operation of chemical plants and their reliable and safe operation (Harvey, 1984).
-Their professional activity will be linked to safety issues and they have moral and legal responsibilities in this matter that they will have to face from the first day of work (Kletz, 1988).

However, debate and reflection have focused on how to integrate safety training into the curriculum (Fleischman, 1988; Harvey, 1984; Kletz, 1988) as a specific subject (Dee et al., 2015; Hendershot and Smades, 2007), compulsory or optional (Mazzarri et al., 2012) or as additional contents to be taught in one or several related subjects (Behm et al., 2014; Hill, 2003; Lane, 1989) such as “Unit operations laboratories” or “Reactor and chemical plant design”, with no agreement yet (Shallcross, 2014; Zeng and Zeng, 2017) and with different approaches.

In recent years, as a result of the recognition of this discipline as an acquired skill by organizations such as the "Institution of Chemical Engineers" or the "International Engineering Alliance", its inclusion as a subject in the curriculum of the Chemical Engineer has been extended (Dee et al., 2015; Shallcross, 2014; Voronov et al., 2017). This decision is based on the fact that it improves the coherence and coordination of the contents, in addition to being taught systematically by teachers with sufficient interest, knowledge, and experience (Perrin and Laurent, 2008), which guarantees the appropriate level of teaching.

The greater experience in the teaching of a Health and Safety program to chemical engineers in Europe has been carried out by the Faculty of Chemical Engineering at the Delft University of Technology (The Netherlands) (Lemkowitz, 1992). It is an integrated program of safety, health, environment, and social aspects that has been taught to the Chemical Engineers of this university since the ‘80s. All program activities are closely related and coordinated and are taught in collaboration with industry.

In the United States, a few years later than in Europe, the Center for Safe Chemical Processing (CCPS) of the American Institute of Chemical Engineers (AIChE) created a program called "Safety and Education of Chemical Engineers" (SAChE program) (SAChE, 2010). Its objectives were to encourage the incorporation of safety content into the chemical engineering curriculum and to develop specific safety content for chemical engineering subjects, to be incorporated into undergraduate and graduate-level education (Louvar and Hendershot, 2003; Mazzarri et al., 2012; Meyer, 2017).

In France, (Perrin and Laurent, 2008) describe the experience of some universities, where safety is taught as a specific subject, and whose contents were proposed according to the guidelines of the "Accreditation Committee of the Institution of Chemical Engineers" complying with the simplified guide of the "European Federation of Chemical Engineering" (European Federation of Chemical Engineering (EFCE), 2010) and with the Bologna ECTS credit schemes. The program allows students to obtain official certifications on intervention in chemical plants at the operator and engineer level validated by the "French Association of Chemical Engineering", and meets the standards set by the ILO-OSH 2001 directive on occupational safety and health management set by the ILO. They also receive the first aid certificate validated by the French Ministry of Health. The curriculum is taught with the collaboration of external experts linked to the industry. Training levels are set to gradually increase the difficulty and achieve better learning (Gillett, 2001).

In 2001, the Accreditation Board of Engineering and Technology (ABET) in the United States reformulated the criteria for the accreditation of chemical engineering programs, including for the first time aspects related to safety and the environment (Felder and Brent, 2003), as other agencies did. Nowadays, accreditation requirements for engineering studies keep on being relevant, which has led many institutions to integrate process safety into existing curricula.

Current safety requirements for accreditation and recognition of the quality of Chemical engineering programs proposed by several agencies are shown in Table 1.

Table 1. Comparison of safety requirements for Chemical engineering program accreditation

Reference	Requirements
ABET (ABET, 2020)	Programs criteria require that the curriculum include analysis and control of the hazards associated with processes. It also considers the importance of providing a safe laboratory environment for the students. General criteria found for BSc and MSc show that one of the outcomes of the students is "an ability to apply engineering design to produce solutions that meet specified needs with consideration of (…), safety, (…) as well as global, cultural, social, environmental, and economic factors. In the case of chemical engineering, remarks that the curriculum must include "engineering application" of the sciences to the design, analysis, and control of processes, including the hazards associated with these processes.
Bologna recommendations (European Federation of Chemical Engineering (EFCE), 2010)	EFCE has formulated its recommendations as program outcomes i.e. what the students should know or be able to do immediately after graduation. Program outcomes for BSc degree include specific references to safety issues, specifically in the topics of: -Investigation: students should be able to make an appropriate safety assessment before starting experimental work. -Engineering practice: students acquire the ability to apply their knowledge of different areas taking safety measures (…) into account responsibly and to extend their knowledge on their responsibility.
IChemE (IChemE, 2015)	Accreditation of chemical engineering programs degree considers Safety, health & environment culture and its practical aspects. In addition to formally taught process safety, IChemE insists that students on accredited degree programs must be instilled with appropriate attitudes to safety, health & the environment (SH&E). The demonstration or otherwise of an adequate safety culture within a department will form part of the assessment, which is a new item, concerning other accreditation programs reviewed. Evidence of effective Safety, Health, and Environment (SH&E) culture includes: -Leadership: Head of Department and Senior Management take an active part in SH&E. -Visibility: clear and relevant signage and information; good standards of housekeeping in laboratories. -Behavior: staff, students, and visitors behave in a careful, risk-averse manner; Personal Protective Equipment is available and usage is enforced; there are systems for incident reporting, follow-up, feedback, and improvement. -Legislative compliance: there is a sound understanding of, and compliance with, applicable SH&E legislation. -Risk assessment and management: Risk assessment and Permit to work systems are in place; those who use them are fully conversant with their roles and responsibilities.
Engineers Ireland (Engineers Ireland, 2014)	Guidelines for Engineering education programs state that "staff and students should receive adequate instruction and safety training to a level commensurate with the work being undertaken". Programs that satisfy the appropriate criteria meet the education standards required to reach Registered Professional Titles of Chartered Engineer, Associate Engineer, and Engineering Technician. For the three levels is asked: "an understanding of the need for high ethical standards in the practice of engineering, including the responsibilities of the engineering profession towards people and the environment".

	Specifically for each professional title, requirements related to safety are the following: -Engineering technician: knowledge of the potential health, safety and risk issues of engineering projects. -Associate engineer: knowledge and understanding of the potential health, safety, cultural and risk issues of engineering technology projects, including the relevant legislation. -Chartered engineer: knowledge, understanding, and commitment to the framework of relevant legal requirements governing engineering activities, including personnel, environmental, health, safety, and risk issues.
Engineers Australia (Engineers Australia, 2009)	Requirements for accreditation of the programs, states an "ability to operate within a broad contextual framework accommodating social, cultural, ethical, legal, political, economic and environmental responsibilities and the principles of sustainable development and safety imperatives". Moreover, practical and "hands-on" experience is required which means proficiency in appropriate laboratory procedures; the use of test rigs, instrumentation and test equipment, a strong grasp of the principles and practices of laboratory safety.

Figure 1 shows a summary of the main milestones in history that have led to the incorporation of safety training for chemical engineers.

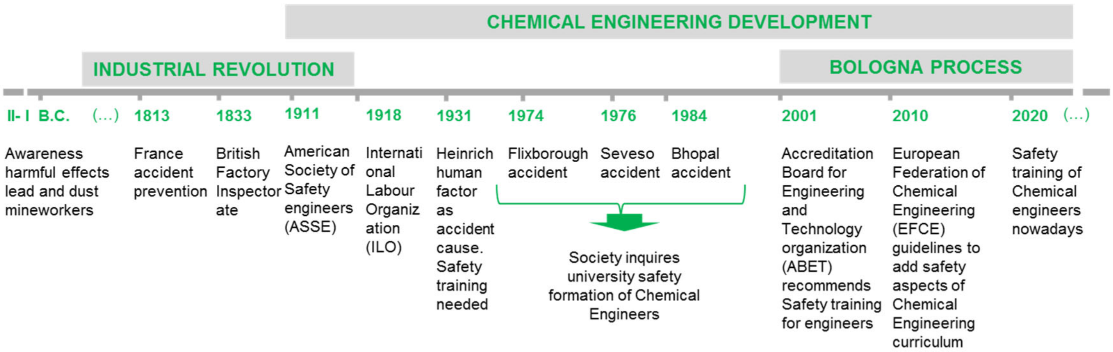

Figure 1. Milestones in history that have motivated the incorporation of safety training for chemical engineers

In summary, the introduction of safety training into the curriculum of chemical engineering in recent decades is allowing the graduation of professionals who are much more aware of the supervision of process safety, making current and future industries and processes safer.

1.2 Safety training for chemical engineers in Spain

In Spain, chemical engineering degrees have not traditionally included safety training, reflecting the situation in the Spanish university environment. Only some engineering degrees (Technical Industrial Engineering or Technical Architecture) have traditionally included some training in safety and occupational risk prevention, required by the professional skills and attributes that these degrees conferred on them. This insufficient, highly variable, and non-systematic presence has made it difficult for students to develop their future professional activity by considering the health and safety of workers and applying the principles of occupational risk prevention (Spanish Ministry of labour and immigration, 2007).

The reformulation of Chemical Engineering degrees to adapt them to the European Higher Education Area was an opportunity to include this subject in the curriculum of chemical engineers. The study plans were designed taking as a reference the White Book of the Chemical Engineering Degree prepared by a network of Spanish universities, supported by the Spanish Agency for Quality Assessment and Accreditation (ANECA) (National Agency for Quality Assessment and Accreditation of Spain, 2005), in which "Safety, Hygiene and Environment" was proposed as a subject within the Chemical Engineering block, as common compulsory content and with an extension of 6 ECTS credits. The minimum contents proposed were:

-Safety in the design and operation of process plants.

-Risk analysis.

-Prevention criteria and strategies

-Safety in the handling of hazardous products.

The skills that the student was expected to acquire in this subject were: the ability to analyze the risks associated with a chemical process, knowledge of safety regulations and the application of protocols in this field, and the ability to handle chemicals.

As a result of this process, two Chemical Engineering degrees were created in Spain at the undergraduate level: the Degree in Chemical Engineering (BSc) and the Degree in Industrial Chemical Engineering (BSc), both of 4 academic years. Their coexistence is because they both come from different degrees previous to the Bologna Plan: the first one arises as an adaptation to the level of the 4-year degree of the previous Chemical Engineering degree (MSc) and the second one, as a transformation of the 3-year degree of Industrial Technical Engineering (BSc), chemical specialty.

In order to verify the incorporation of safety training in these new degrees, the study plans of the new Chemical Engineering degrees that are in force for the 2019-2020 academic year were consulted, and an analysis was made of whether this discipline is included in the study plan and how (as a specific subject or included as part of other subjects), the type of subject (compulsory or optional), the course in which it is taught and the number of ECTS credits. The information was collected by the authors through the websites of the Spanish universities where chemical engineering studies are taught. These university degrees are official and for their verification, the study plans have been submitted for approval following the guidelines of Spanish Royal Decree 1393/2007. A total of 40 degrees were analyzed, 11 of which were Degree in Industrial Chemical Engineering, and 29 of which were Degree in Chemical Engineering.

The results are shown in Figures 2 and 3.

The Degree in Chemical Engineering is taught in 29 Spanish universities. Figure 2 shows that the study plans include specific subjects on Safety (in 66% of cases), although they are mostly optional (63% of cases). They are taught in the 4th year (80% of cases) and range from 4.5 (35% of cases) to 6 ECTS in most cases (40% of cases).

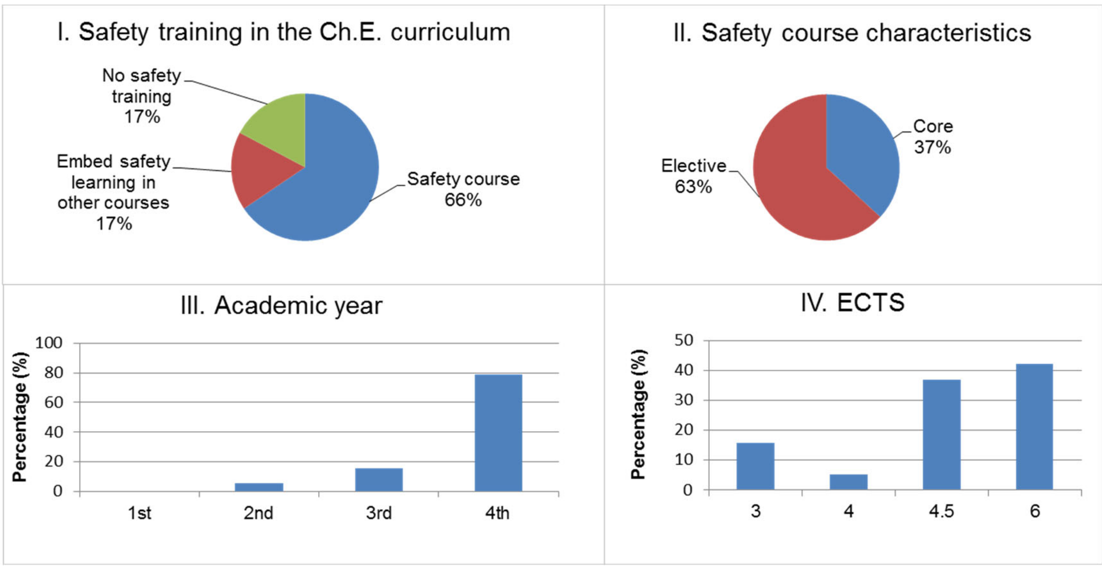

Figure 2. Analysis of the teaching of safety in the Chemical Engineering Degree in Spain

The Degree in Industrial Chemical Engineering is currently taught in 11 Spanish universities. Figure 3 shows that specific safety subjects do not predominate in their study plans (only 45% of the cases), being in most cases obligatory (80% of the cases). The course in which it is taught is 4th (60% of the cases) and 3rd (40% of the cases) and in most cases, it has an extension of 6 ECTS (60% of the cases) and in the rest, it has 3 ECTS.

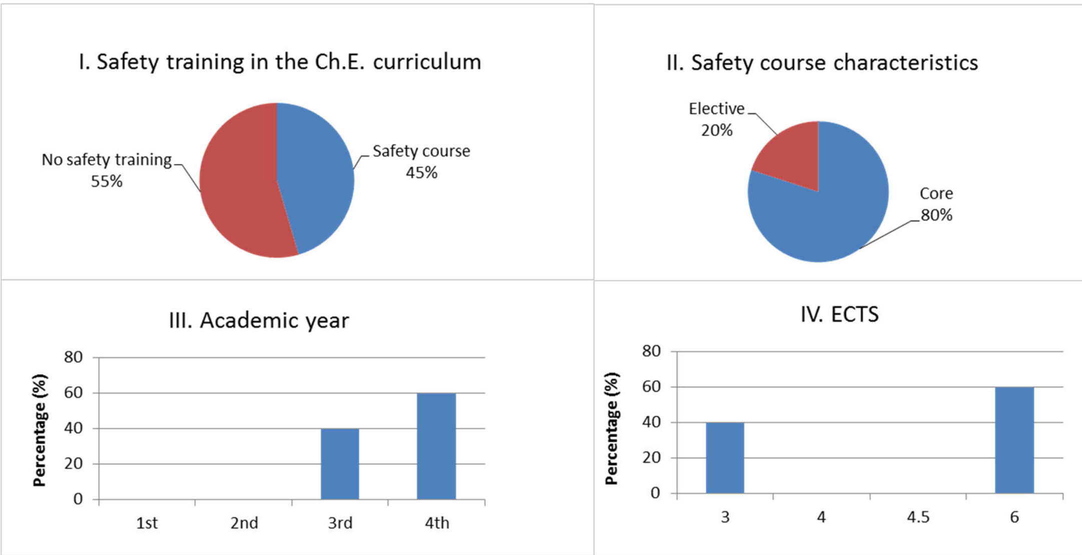

Figure 3. Analysis of the teaching of safety in the Degree in Industrial Chemical Engineering in Spain

These results make it clear that safety training is not included in the majority of Chemical Engineering curricula in Spain, despite the commitment of the educational and labor authorities to promote training in safety and occupational risk prevention at the university level, and the importance of this training for future Chemical Engineering graduates. Despite this, since the implementation of the Bologna Plan, a lot of progress has been made, increasing its presence that, in general, is a specific, final year subject with 4.5 or 6 ECTS credits assigned.

2. Analysis of the curricular and methodological approach to learning-teaching in Safety for Chemical Engineers

2.1. Content for safety training: analysis of Spanish universities

According to (Shallcross, 2013), a list of themes that all chemical engineer must know and be able to apply to resolve safety problems in the industry would include the following:

-laws and safety standards.
-rights and obligations for employer and employee about safety.
-fire prevention and protection.
-hazards of working with chemicals, toxic material, and hazardous wastes.
-work permits and procedures (including confined spaces).
-safety management systems.
-emergency plan.

-human factor and its influence on safety.

-process control.

-hazards associated with maintenance and servicing.

-risk identification and minimization strategies.

-design with inherent safety.

-hazards associated with reactive systems.

These contents are in line with SAChe recommendations (2010) and the White Book of Chemical Engineering in Spain (National Agency for Quality Assessment and Accreditation of Spain, 2005).

In order to find how these recommendations have been incorporated in the new Chemical Engineering degrees that are currently taught in Spanish universities, an analysis of their curriculum has been made. For that purpose, it has been revised each curriculum, the subjects where safety contents are taught and the type of contents taught consulting their teaching guides and structuring them in the preventive disciplines to which they correspond: Industrial Safety, Industrial Hygiene, Occupational risk prevention, and Other aspects. The results of this study are shown in Figures 4 to 7.

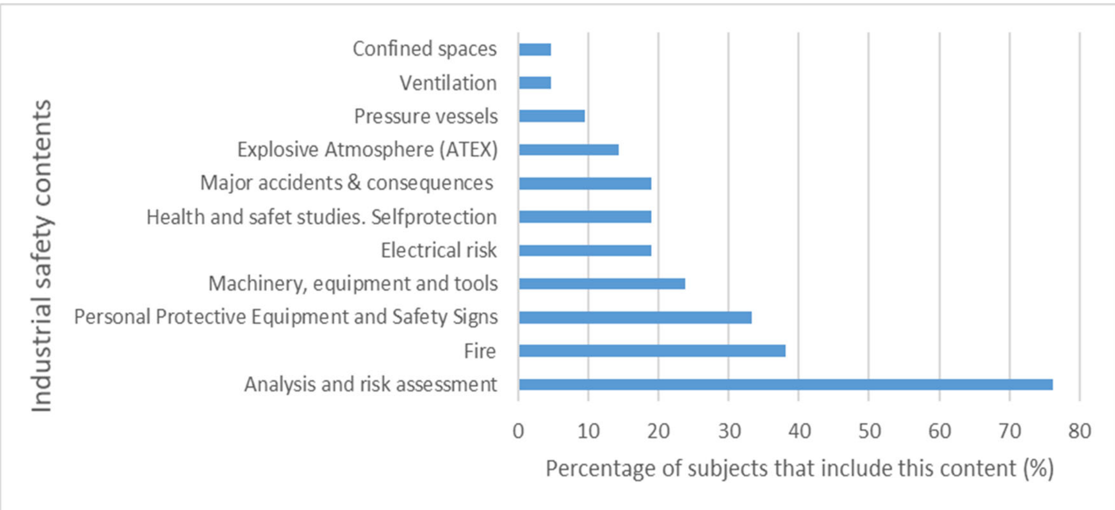

Figure 4. Contents on Industrial Safety in subjects of Safety in Chemical Engineering degrees at Spanish universities

Of the 40 degrees, 21 teach contents about Industrial safety. As can be seen in Figure 4, 75% of the subjects include content about safety, analysis, and risk assessment. The other most commonly discussed topics are fires, Personal Protective Equipment and Safety Signs in 30% of cases, and machinery, equipment and tools in 25%. Other topics as electrical risk, self-protection, explosive atmospheres, or ventilation are treated as a minority in the subjects.

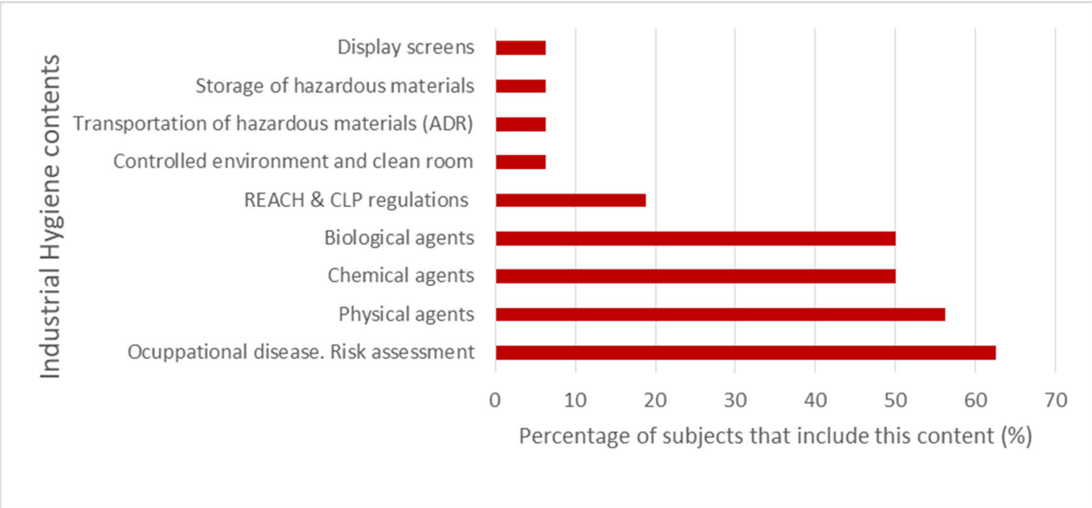

Figure 5. Contents on Industrial Hygiene in subjects of Safety in Chemical Engineering degrees at Spanish universities

On the other hand, 16 Spanish universities teach content on Industrial Hygiene. The most discussed topics, as can be observed in Figure 5, are the concept of hygiene, occupational disease and hygiene risk assessment (in 60% of cases), as well as physical, chemical and biological agents (in 50% of cases). Aspects like the REACH and CLP regulations for Classification, Labelling and Packaging of chemical products or the storage of hazardous materials are less common.

Concerning prevention topics, only 7 degrees teach these contents, as can be seen in Figure 6.

Figure 6. Contents on Occupational Risk Prevention in subjects of Safety in Chemical Engineering degrees at Spanish universities

These are in the minority compared to those of health and safety, the most discussed being those related to prevention management.

Finally, Figure 7 shows other contents that are dealt with in safety subjects.

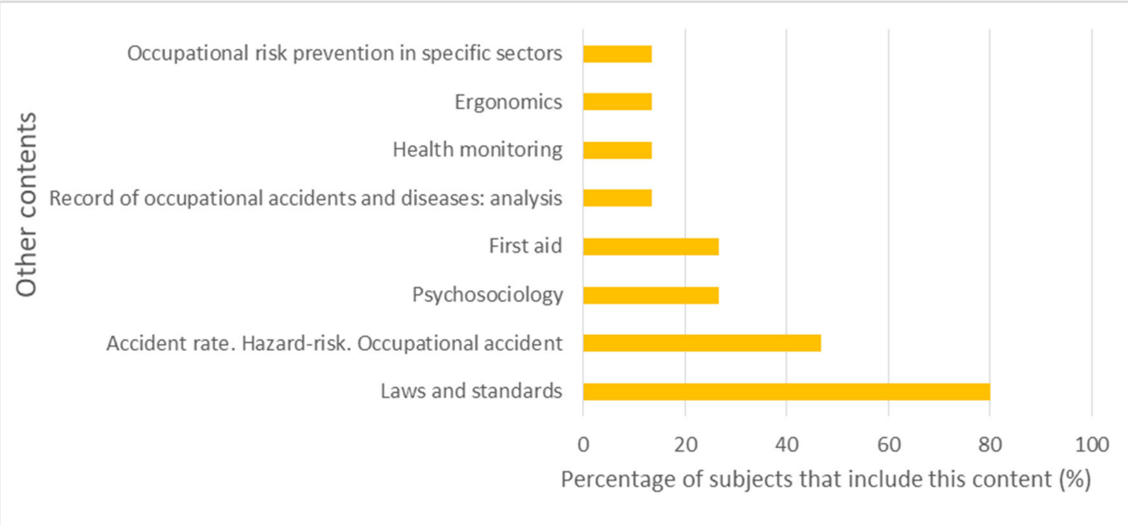

Figure 7. Other contents included in subjects of Safety in Chemical Engineering degrees at Spanish universities

The majority of the contents are legislation (laws and standards), although other topics are also discussed such as accident rate, the concept of hazard and risk and occupational accidents, or psychosociology and first aid.

From this analysis, it can be concluded that safety training for chemical engineers is mostly in the area of industrial safety, followed by industrial hygiene, with occupational risk prevention being in the minority. The use of specific legislation and regulations to support the topics developed is noteworthy.

2.2. Applied methodologies for safety training

Since the aim is to train future professionals capable of identifying, selecting, evaluating and comparing the different alternatives for solving safety problems during their working life independently and optimally, it is necessary a learning-teaching methodology based on reasoning (Ferjencik, 2007) that promotes the active role of students in building their learning and transferring it to real situations (De Miguel, 2005), thus approaching the professional role they will play shortly. International chemical engineering associations agree that safety education must include, beyond concepts, active resolution methods (Meyer, 2017).

Therefore, one of the strategies that can be implemented is the use of active methodologies, understood as those methods, techniques, and strategies that the professor uses to convert the teaching process into activities that encourage active student participation and lead to learning (Labrador Piquer and Andreu Andrés, 2008). In this way, creative thinking about safety is promoted, as well as the identification of alternatives, comparison, selection, and evaluation of these for the search of solutions to specific problems (Darbra et al., 2012; Ferjencik, 2007).

There are some documented experiences on the use of these methodologies in the teaching-learning of Industrial Safety for Chemical Engineers with good results:

- Case study: It is an active methodology that favors learning by discovery, logical reasoning and organization, the search for information through the study and discussion of real situations, close to the professional life of the future engineer. There are some experiences found which are based on an analysis of real accidents (Ferjencik, 2007; García Fayos et al., 2017). The aim is to determine the main causes of these accidents and to identify risks and preventive measures needed to prevent or minimize the consequences.
- Role-playing: This methodology consists of providing students with a role or character that they must play in the safe environment of the classroom, to learn how to behave effectively when they are in the real working environment. Some experiences found (García-Fayos et al., 2012; Graells and Perez Moya, 2007) use real cases in which students act as “experts” or safety advisors who investigate an accident, explaining the case, the causes and its solution (Darbra et al., 2012). This methodology increases the interest and involvement of the students, as they feel they are working on a real case. Also, it allows for the development of teamwork and creativity.
- Safety shares: understood as a 2-4 minute discussion on some topic of safety, as it is done in real companies (Shallcross, 2014), where a real culture of safety and occupational risk prevention is implemented.
- Seminars (García Fayos et al., 2017; Shallcross, 2013) about specific topics of industrial safety. This methodology allows them to work in greater depth on the

contents, as well as to work on other skills such as oral presentation and communication skills when presenting and defending the cases studied.

- Project-based learning: It is a teaching-learning method in which students carry out a project in a given time to solve a problem or tackle a task by planning, designing, and carrying out a series of activities. The projects focus on problems or topics related to the basic concepts and principles of one or several subjects (multidisciplinary character) and generate new knowledge. It is a method recommended in terminal subjects, where the contents of different areas of knowledge are integrated (De Miguel, 2005). Among the numerous advantages of Project-based Learning, the following could be highlighted (Fernandez, 2006): the development of self-learning and creative thinking, the improvement of motivation, the integration of learning and the acquisition of a professional work methodology since it makes it possible for the student to approach a business "reality". As it is a multidisciplinary methodology, it easily allows the integration of safety with other disciplines, both with theoretical and more applied approaches. Thus, there are also experiences of integrating safety through project-based learning using the laboratory as a real learning scenario (Sancho et al., 2007).
- Cooperative learning: It is a teaching method in which the students work in small groups developing a learning activity to reach a common goal, making the resulting productivity much higher than the best production of any of the components of the team. There are documented experiences on the use of this methodology in Chemical Engineering studies (Felder and Brent, 2003) that demonstrate the efficiency of this method compared to the traditional system. Once the students have been trained and adapted to this methodology, and the difficulties for cooperation have been overcome, the students achieve a greater and deeper learning and a more positive attitude towards the subject where it is applied (Felder and Brent, 2003; Maceiras et al., 2011).

Besides, there are experiences on safety learning in experimental subjects that are taught in laboratories (Arnal et al., 2009; Peñas et al., 2006), since they provide a real environment where many of the contents related to safety and awareness of its importance can be put into practice through experimentation, self-learning, and training (Abu-Khalaf, 2001).

3. Example of safety training for chemical engineers

This paper presents the case of the experience developed in the teaching of safety in the Chemical Engineering Degree at the Universitat Politécnica of València in Spain.

3.1 Course Design

The subject in which safety training is carried out is “Industrial Safety”, a fourth-year semester B subject, of an optional nature and 4.5 ECTS. The average number of students is 15 per academic year. This is a newly created subject for chemical engineers, which came about after the creation of the Chemical Engineering Degree in 2010 due to the Bologna process, given that in the previous curricula there was no safety training.

The following considerations have been taken into account for the design of the course:

- Previous knowledge of the students

The learning in safety in the degree has been proposed as mixed learning through a transversal approach, embedded in experimental and theoretical compulsory subjects of the second, third and fourth year, and specifically through the optional subject “Industrial Safety”. The compulsory experimental subjects in which safety aspects are developed are Experimentation in Chemical Engineering I (2^{nd} year, semester B), II (3^{rd} year, semester A), and III (3^{rd} year, semester B). These experimental subjects are used for students to learn and put into practice their knowledge of safety and health in a real environment such as the laboratory. Chemical risk is specifically worked on through the use and interpretation of the Safety Data Sheet (SDS), H and P phrases, pictograms, personal protective equipment, and action against spills of the chemicals they use. Furthermore, in their laboratory report, students identify risks and propose preventive measures for the equipment and materials they use and integrate them in the preparation of a work procedure.

Afterward, students take the compulsory course “Industrial Processes in Chemical Engineering” (4^{th} year, semester A). In this course, cooperative learning is implemented, combining theoretical concepts with the analysis of accidents to deepen in aspects related to dangers associated with the use of inflammable substances. The methodology applied is similar to “safety shares” (Shallcross, 2014).

- Lecturers who teach the subject

To facilitate coordination with previous subjects, it is convenient that the subject is taught by lecturers who also teach one or more of these. This will allow coordinated, systematic, and structured teaching to take place. Also, lecturers who teach the subject must be genuinely motivated and safety-conscious to convey to students the importance of the subject, so that it becomes part of their professional life (at the beginning of their working life and throughout their lives) and ethics (even outside work) (Hill, 2004).

In the case of this subject, the teaching staff is composed of three lecturers: one is a professor and two are associate professors, which are Chemical engineers (Ph.D.), with a Master's degree in Occupational Risk Prevention, and Master's degree in industrial safety and the environment. Regarding their industrial experience, one of them worked for 10 years in the construction sector and assembly and repair of industrial and mechanized machinery. All of them collaborate also as consultants for companies in the exposure to asbestos, issuing expert reports on accident and fire investigation, and in research on nuclear accidents. Moreover, one of them has also been responsible for safety for more than 20 years in the Department of Chemical Engineering and the Institute for Industrial, Radiophysical and Environmental Safety (ISIRYM) of the UPV, which supervises safety in the teaching and research activities of more than 75 professionals.

Finally, it should be noted that the teaching staff has been integrating safety transversally into experimental Chemical Engineering subjects (Arnal et al., 2009) and teaching subjects in the Master's Degree in Occupational Risk Prevention for more than 15 years.

This academic formation and professional experience make lecturers selected to teach this subject qualified and motivated to impart this discipline.

- Contacts with external companies

The collaboration of professionals from external companies is fundamental to provide students with a practical and real approach to the application of the subject. Preferably, they will be graduate chemical engineers who will transfer their professional experience on safety and risk prevention in the industry to future chemical engineering graduates. In the case of this subject, are graduates of Industrial or Chemical engineering (MSc) from UPV who work in engineering and consulting companies specialized in Safety and Health studies or ATEX and firemen of the Provincial Fire Consortium of Valencia (Spain).

3.2 Contents and Teaching methods

3.2.1 Content proposal

Based on the information analyzed in section 2.1 it has been decided to structure the subject in the didactic units shown in Table 2 together with the number of hours dedicated to each one.

Table 2. Programming of didactic units for the subject

Didactic unit	**Dedicated hours**
1. Basic principles of Industrial Safety	6
2. Basic principles of Industrial Hygiene	6
3. Risk Identification	10
4. Risk Assessment	5
5. Preventive measures	6
6. Personal protection equipment & First aid	4
7. Storage of chemical products	2
8. Pressure Vessels	2
9. Explosive atmospheres (ATEX)	2
10. Fires	2
Total	45

As can be observed in Table 2, the didactic unit with a greater percentage of hours dedicated to the subject is the "Risk identification" (10 hours), followed by "Basic principles of Industrial Safety and Hygiene" (6 hours each). The group composed of "Risk identification, assessment, and preventive measures" constitutes the core of the subject and is in line with the most present topics developed in subjects of Safety in Chemical Engineering degrees at Spanish universities analyzed previously in section 2.1.

The didactic units shown are developed through the methodology and activities described in the following section.

3.2.2 Methodological proposal

Concerning the methodology, it is proposed a useful and practical teaching-learning methodology to acquire, not only knowledge but also the ability to know what to do and how to do it under certain circumstances. These objectives are shown in Figure 8.

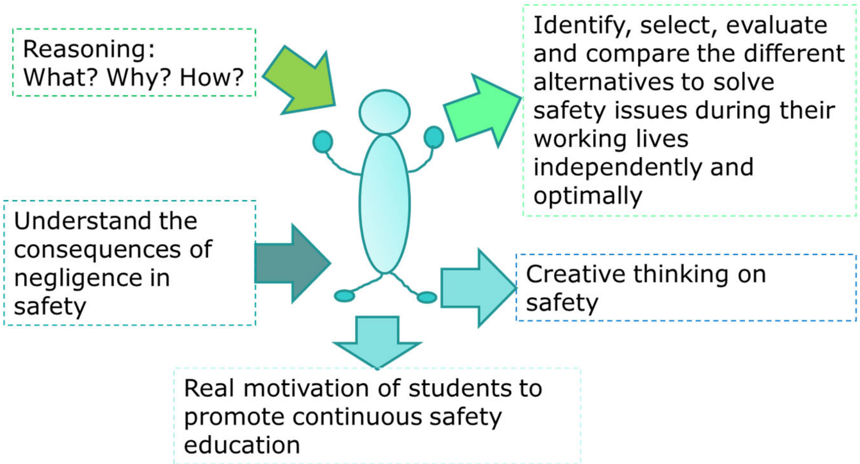

Figure 8. Methodological objectives for useful and practical teaching on safety for chemical engineers

Taking into account the analysis of the methodologies proposed by other authors that have been discussed in section 2, different active methodologies (apart from participative master class), have been selected and integrated for the development of the contents, to increase the motivation of the students and the acquisition of more autonomous and integrative learning. Then, the selection of each methodology is justified and how it has been integrated into the course is described:

A) Project-based learning

Project-based learning has been selected as the main methodology of the course because of the educational advantages it offers to students, especially in the last academic years of their studies: an approach to professional work, multidisciplinary character, development of high-level skills, as well as transversal skills (teamwork, oral and written communication, etc). Also, the team of teachers of the subject has significant experience in the application of this methodology in contexts where the discipline of safety is worked on (such as experimental subjects), having obtained very satisfactory results (Arnal et al., 2012, 2011).

The unifying thread of the course will be the elaboration of a project, consisting of a health and safety study of an industrial process that includes the analysis of all the stages of the process, the machinery, and the exposed workers. The selected industrial process is the one described in the core subject of semester A, “Industrial processes in Chemical Engineering”: the extraction process for obtaining olive oil. This process includes reception, feeding, de-leafing, watering, breaking, grinding, thermo-mixing of the olive paste, oil extraction using centrifugation and the final separation of the oil. The process can also include drying of the raffinate and solid-liquid extraction of residual oil with organic solvents. The project will be carried out in groups of 3 to 5 students. To develop it, the students will obtain information and learn procedures from different activities carried out throughout the course, related to the Project. Table 3 shows these activities and the content of the course-related.

Table 3. Subject activities related to the Project

Content of the course	**Activity related to the Project**
Basic principles of Industrial Safety	Accident rate analysis in the sector and the company
Basic principles of Industrial Hygiene	Identification of physical, chemical or biological agents in the industrial process
Occupational risk prevention management	Health and safety organization chart
Risk identification	Risk identification of the process (products, equipment, and workers)
Risk assessment	Risk assessment using Fine methodology (Fine, 1971)
Preventive measures	Preventive measure to reduce the risk level
Storage of chemical products	Design of storage of chemical products used in the process

B) Role-playing

Role-playing has been selected as a methodology of the course because of the approach that it implies for the students to the professional reality, allowing them to face different approaches (safety inspector, worker, etc.) that enrich their training in this discipline. Another reason for selecting it has been the potential for the motivation of the students, as it has been mentioned before, and that has been confirmed by our students, as it will be seen later in section 4.1.

In Industrial Safety, this methodology is used for students to play the role of safety inspectors or workers in the industry that is the object of the project. Figure 9, shows a schematic of the role-playing methodology implemented in which students acquired progressive skills of safety inspectors playing from a known environment (lab), to simulated plant until real industrial plant.

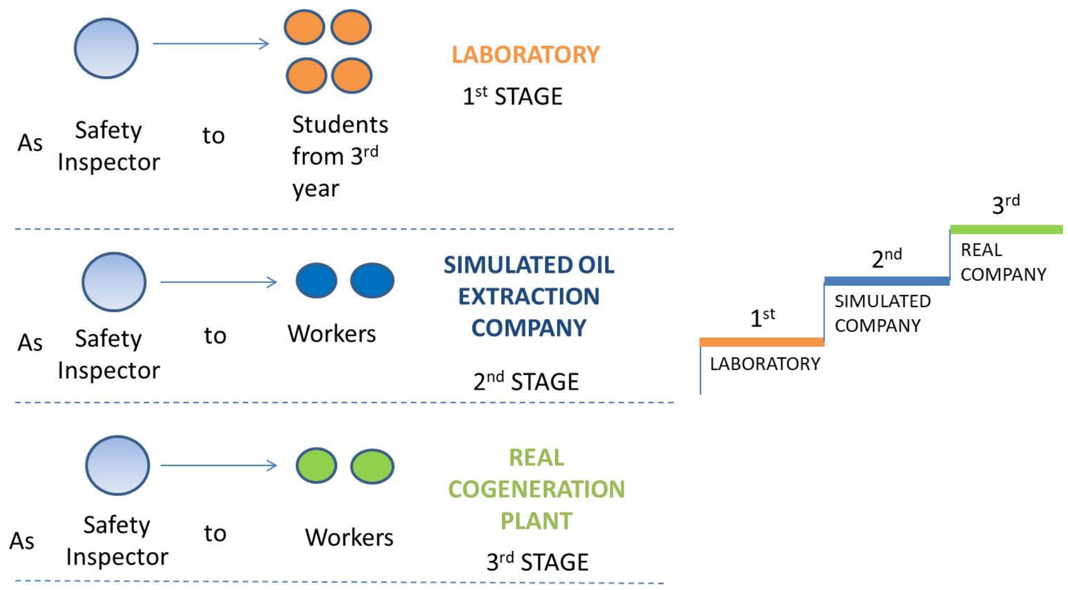

Figure 9. Role-playing methodology for the development of safety inspectors skills

Specifically, the following activities are developed:

- Visit the laboratory of the Chemical Engineering Department during an experimental session of the subject “Experimentation in Chemical Engineering III” (3rd year, semester B). The students, in their role as safety inspectors, have a checklist to facilitate the observation of the existing safety measures in the laboratory and the risks to which the students are exposed. The inspection consists of observing the work procedures of the 3rd year students who are carrying the experimental practice consisting of solid-liquid oil extraction by using acetone, the possible incidents that may occur, identifying the preventive measures that are implemented and the adequacy of the personal protective equipment that the students use based on the hazardousness of the chemicals handled.

- Safety inspection to a simulated industry. In this simulation, some lecturers and students will play the role of workers in the chemical industry on which the project is based. The rest of the students will play the role of technicians of occupational risk prevention and will ask questions to those who play the role of workers to extract the necessary information that will allow them to identify the main risks of each represented job, as well as evaluate them. For this, the students playing the role of workers will have a script with the guidelines of the role to be played both in work functions and the conditions in which they develop their work as accurately as possible in regards to reality.

- Visit a real chemical industry. The students, accompanied by the lecturer, visit an industry. The visit aims are to identify the risks of the process and the preventive measures available, through the observation of the process and the questions asked to the workers of the company visited. Some of the risks have been previously analyzed in the laboratory and the visit to the simulated company.

C) Case study

The case study has been selected for the course because it allows the integration of one of the analytical techniques used in safety, such as accident investigation. This technique is very motivating for the students because they work with real accidents and, also, it allows them to work on the competence of ethical responsibility through the discussion of causes and the assignment of responsibilities.

In the course, two cases are studied in which the students are expected to acquire practice in the analysis or evaluation of critical situations from a safety point of view. Specifically, they study the Bhopal accident, which is the most severe accident in the history of the chemical industry, and the Tianjin accident, which took place in 2015 in a chemical storage facility and was aggravated by the techniques used to extinguish the fire caused:

a) In the case of the Bhopal accident, students watch two videos about it. In the first video, a representation of what happened in the hours before the accident is shown. After this, students are asked to argue on paper the sequence of the accident, the causes, and the main culprit of the accident. The second video is then shown, giving a technical explanation of the causes of the accident and commenting on how the responsibilities for it were established in reality. The session concludes with a classroom debate in which students explain from their point of view the assigned responsibilities of the accident and compared them with those that occurred in reality.
b) In the case of the accident in Tianjin, first, the lecturer contextualizes it and a video is shown with real images of it. Later, students must look for the Safety Data Sheets of some of the chemicals involved in the accident to extract, among other information, the hazards of these substances, their incompatibility of joint storage, and the unsuitable extinguishing agents. With all this, a global

discussion is established in which students try to clarify the possible causes of the accident and the preventive measures that could have minimized its consequences.

D) Cooperative learning

This methodology has been selected because it allows students to work similarly as they would in a real professional environment, where safety is dealt with in work teams, which are also multidisciplinary in most cases. Thus, students work on skills beyond the specific ones that prepare them more completely for their professional work (Felder and Brent, 1994). In this course, cooperative learning is used in the following activities:

- *Introduction to Industrial Hygiene*. Sharing the identification of physical, chemical and, biological agents of an industrial process. The activity consists of dividing the students into groups of 3-4 members to visualize some videos about an industrial process. Each group will visualize the videos corresponding to a part of the process and will try to identify the physical, chemical, and biological agents that appear in it and how workers can protect themselves against them. Once the visualization is completed, each group will discuss the preventive measures observed and provide ideas for additional measures. Afterward, each group will expose the conclusions to the rest of the groups and the lecturer. As a result, students obtain the identification of physical, chemical and, biological agents of the industrial process.

- *Risks identification*. After the role-playing activity explained previously of visiting the laboratories during the development of experimental sessions, a classroom session is carried out which consists of sharing results from the identification of risks in the classroom. Each student (if the group size is small) or each group (if the group size is large) will expose the main risks for each element and chemical product used, as well as consequences and preventive measures needed.

- *Preventive measures*. After the role-playing session of safety inspection in a company, also described previously, a computer practice is carried out where, with the help of the Excel program, the students perform the risk assessment following Fine methodology (Fine, 1971). Once assessed, preventive measures must be proposed for the most important risks, i.e. those classified as intolerable and important. In the following classroom session, a group tutorial session is developed in which the students elaborate their proposal of preventive measures and obtain feed-back from lecturers. Each group will work on different preventive measures, associated with the workplace assigned. After that, the proposal of preventive measures of each group will be put in common to have an overall vision of the main preventive measures in the whole industrial process.

As a summary of all the methodology described, Table 4 shows the specific methodology applied in each didactic unit, and the most relevant activities carried out.

Table 4. Methodology and activities of each didactic unit

Didactic unit	**Methodology used**	**Principal activities**
1. Basic principles of Industrial Safety	-Participative master class -Case study: Bhopal accident	-Consulting of official sources for accident analysis -Reflection and discussion about failures chain and ethical responsibilities in an accident -Resolution of an initial survey about safety theoretical concepts -Video visualization of an accident
2. Basic principles of Industrial Hygiene	-Participative master class -Cooperative learning	-Video visualization of an oil production process -Identification and explanation of hygienic risks and preventive & corrective measures observed. -Work procedure based on SDS application
3. Risks identification	-Role-playing -Cooperative learning	-Visit the laboratory as safety inspectors -Visit a simulated oil company as safety inspector or worker -Visit real companies (flour making company, pump machining and repair small company or combined cycle plant)

		-Shared resolution of risk identification in the laboratory
4. Risks assessment	-Participative master class -Role-playing	-Visit a simulated oil company as safety inspector or worker -Computer practice application of the Fine methodology (Fine, 1971)
5. Preventive measures	-Cooperative learning -Role-playing	-Group tutoring for preventive measures proposal using legislation requirements. -Simulated visit to an oil company to expose preventive measures needed.
6. Personal protection equipment & First aid	-Participative master class -Role-playing	-Practical application of cardiopulmonary resuscitation
7. Chemicals storage	-Participative master class -Case study: Tianjin accident	-Search and reading of legislation and Safety Data Sheets for the design of a chemical storage
8. Pressure equipment	-Participative master class	-Search and reading of legislation
9. Explosive atmospheres (ATEX)	-Participative master class	-Industry experts talk
10. Fires	-Participative master class	-Industry experts talk

4. Results and analysis

This section will analyze the results obtained after the implementation of the planning, contents, and methodologies explained in the previous section, from the 14-15 academic year.

The results analyzed, reflect the opinion of the students regarding the contents and activities carried out in the subject, as well as their self-evaluation regarding the degree of learning achieved in certain professional skills related to safety. On the other hand, the level of learning achieved by students who have taken this optional subject is collected, as opposed to students who have only taken compulsory subjects (experimental and theoretical-practical), in which safety aspects are dealt with in a transversal way. In total, the answers to the surveys carried out anonymously by the 80 students who have taken the subject throughout the academic years have been analyzed, as well as the files of grades obtained by the students in the subject of “Industrial Safety” and the previous compulsory subject of “Industrial Processes of Chemical Engineering”.

4.1 Student assessment of the contents and activities carried out

To know the opinion of the students about the usefulness of the contents taught for their professional future as well as their assessment of the activities carried out, a survey is performed. The students are asked to assess the didactic units and the activities carried out. The survey is anonymous and each item is evaluated with a four-level Likert scale (Very good, good, regular, and improvable). The survey was carried out from academic year 14-15 to academic year 19-20 except for academic year 16-17, and a total of 80 students answered. The results obtained for each content and activity have been transformed to base 10, assigning each level a score (Very good=10, Good=7.5, Regular=5, and Improvable=3), and calculating the average of the global score for each didactic unit.

Table 5 shows the result of the assessment of the didactic units (score over 10), as well as the methodologies implemented, the number of activities carried out, and the hours dedicated to each one of them according to the information of the Tables 2 and 4.

Table 5. Assessment of the teaching units

No.	Didactic unit	Score	Methodology				No. activities	Hours
			Particip. class	Case study	Role-playing	Coop. learning		
1	Basic principles of Industrial Safety	8.9	X	X			4	6
5	Preventive measures	8.9			X	X	2	6

3	Risks identification	8.7			X	X	6	10
6	Personal protection equipment & First aid	8.7	X		X		2	4
4	Risks assessment	8.6	X		X		2	5
10	Fires	8.5	X				1	2
9	Explosive atmospheres	8.4	X				1	2
2	Basic principles of Industrial Hygiene	8.4	X			X	2	6
7	Chemicals storage	8.3	X	X			1	2
8	Pressure equipment	8.2	X				1	2

Table 5 shows that the average score obtained for all the didactic units is above 8 out of 10 in all cases. The best-rated didactic units are (1) Basic principles of Industrial Safety, (5) Preventive measures, (3) Risks identification, (6) Personal protection equipment & First aid, and (4) Risk assessment. Furthermore, it can be seen that the didactic units with the highest marks are those in which a greater number of activities have been carried out, and in which methodologies are combined, especially the participative master class with another active methodology (case study, role-playing or cooperative learning) or even several active methodologies (as role-playing with cooperative learning). In particular, it has been observed that role-playing activities (as visit the laboratory as safety inspectors or visit a simulated oil company as safety inspector or worker) are the best valued, as they motivate students and make them play a role close to their professional reality.

Concerning the hours dedicated, students generally value better those didactic units to which more time has been dedicated, with dedications of 4 hours or more, except for the "Basic principles of Industrial Hygiene". In this didactic unit, changes have been made throughout the academic courses regarding the contents and material used, which has caused this qualification on average, although in the last two courses the same contents and material have been taught, obtaining a slightly higher average qualification (8.55 out of 10).

Therefore, students perceive as positive for safety learning the use of active methodologies, the combination of the master class with active methodologies, the performance of at least a couple of activities for each didactic unit, and an hourly dedication of 4 hours or more for teaching-learning.

4.2 Student assessment of the degree of learning achieved in professional skills

The degree of learning of the students has been assessed in certain professional competences and skills related to safety that have been worked on during the course and that will be useful in the development of their professional activity as chemical engineers. For this purpose, they have been asked to carry out an anonymous survey at the end of the course, to assess their level at the beginning of the course and after it. The questionnaire contained the following questions about the assessment of their level in:

a) Identification and understanding of current situations related to Industrial Safety (e.g. interpretation of news, real cases, etc.)
b) Proposal of technical solutions with critical judgment in a real situation (For example: identify risks in a workplace and prioritize preventive measures)
c) Management and enforcement of legislation related to safety
d) Consultation of bibliographic sources specialized in safety

The self-evaluation of the level of each student was requested based on a Likert scale of four levels (None, Low, Medium, and High).

Figures 10 and 11 show the results for the 4 competencies analyzed.

The results obtained show that, on average, for the four competencies analyzed, the initial level considered by the students is none or medium in 81 % of the cases, with the low level prevailing in 45.9 % of the cases, and after taking the course they claim to have reached a medium or high level in 91.5 % of the cases, with the medium level prevailing in 49.8 % of the answers provided. Therefore, it is possible to state that the subject and methodologies used helps to improve the degree of learning in these competencies in the students in at least one level, going from low to medium on average.

The specific analysis by competencies is carried out below.

Figure 10 shows the average results for the first two competencies (“a” and “b”), obtained from academic years 15-16, 17-18, 18-19, and 19-20.

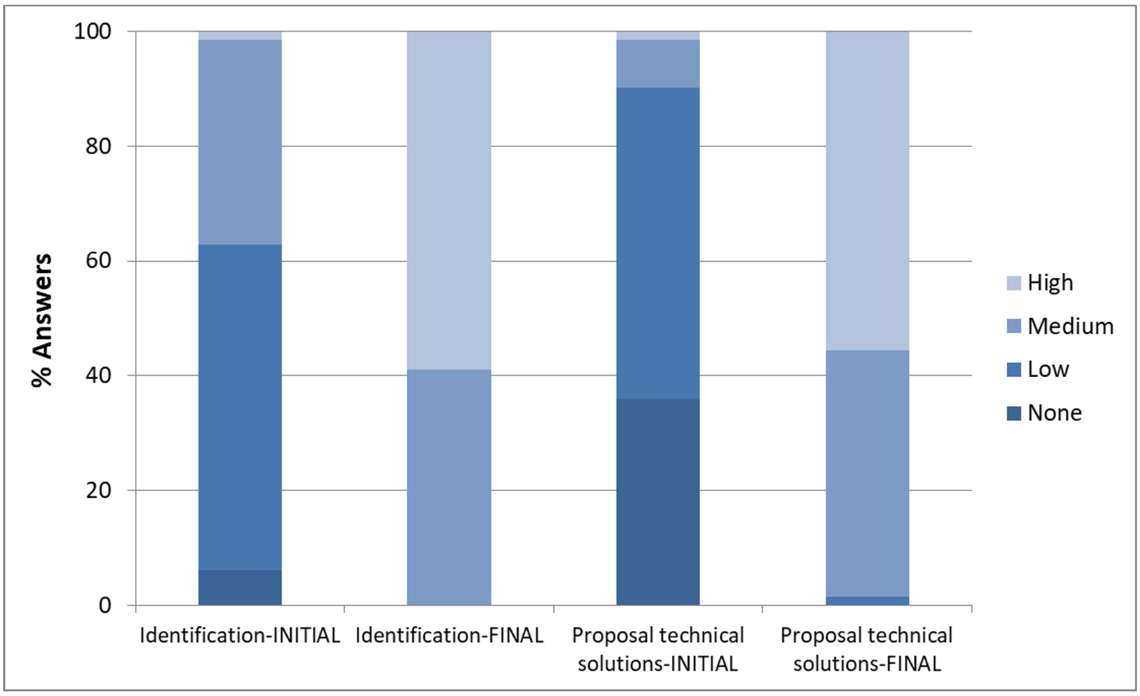

Figure 10. Assessment of the degree of learning in understanding safety situations and technical proposal of solutions

It is observed that for the "Identification and understanding of current situations related to Safety" competence, the initial level is valued as none or low in 63% of the cases, being valued after taking the subject as medium (41%) or high (59%), which implies that the students perceive that taking this subject has allowed them to improve their level in this competence, reaching a high level in 60% of the cases.

For the case of "Proposal of technical solutions with critical judgment in a real situation", the results are similar to the previous case. The initial level is assessed as none or low in 90% of the cases, reaching after a medium or even high level in 98% of the cases, with a majority assessment of high (55.7%). This competence is very useful for future engineers since in the performance of their work they will encounter situations of lack of safety to which they must put solutions by applying the technical knowledge acquired throughout their studies.

Figure 11 shows the average results for competencies “c” and “d”, obtained from academic years 15-16, 17-18, 18-19, and 19-20.

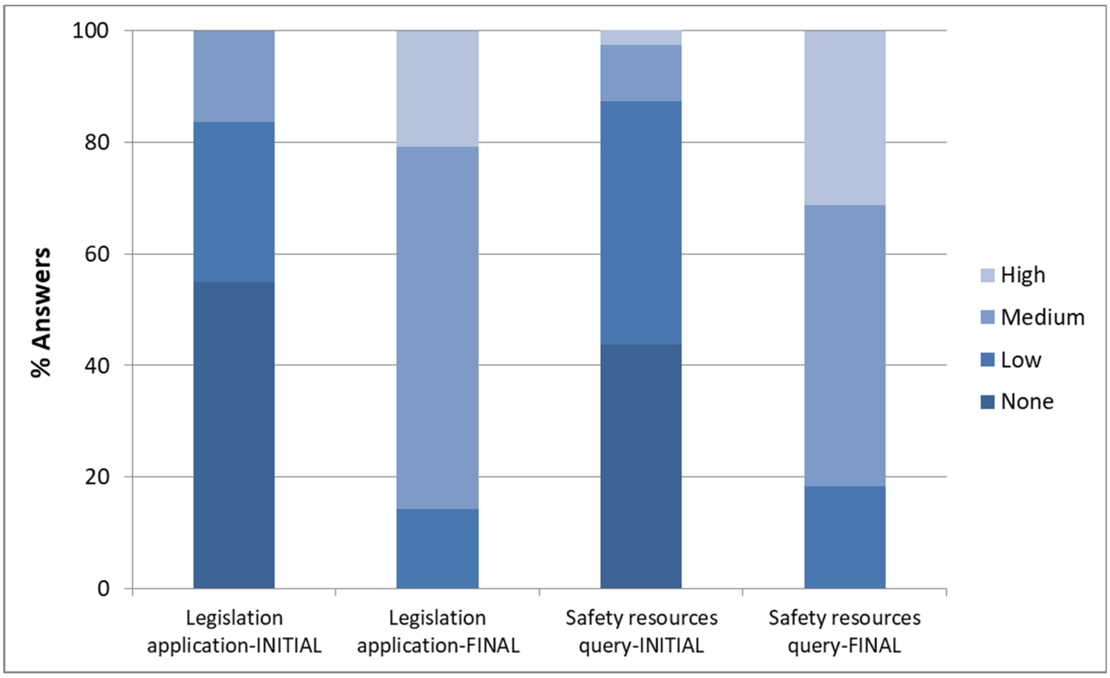

Figure 11. Assessment of the degree of learning in the use of legislation and consultation of safety literature

The figure shows that for the competence "Management and application of legislation" the level of students are qualified as none or low in 83.7% of the cases, prevailing the level of none with 54.9% of the cases. The final level is mostly medium or high (85.9%), with the medium level being the majority with 64.9%. Management and enforcement competence is fundamental for chemical engineers since it provides the legal framework on which technical solutions are based. Most of the students have never consulted or read legislation previously because is a great effort for them due to the type of language used. It also requires a high level of understanding as they must subsequently know how to apply this information in the search for a solution. The subject contributes to the improvement of this level according to the opinion of the students.

Finally, there is the competence "Consultation of bibliographic sources specialized in Safety", the initial level is none or low in 87.4 % of the cases, being after taking the subject medium or high in 81.7 % of the cases, highlighting the medium with 50.4 % of the cases. Access to bibliographic sources, searching for them, and reading them is a useful skill when it is necessary to search for information or references that can contribute to solving a technical problem. Discrimination between reliable and unreliable sources is fundamental for the rigor of the process and the results obtained.

4.3 Assessment of the influence of the safety course on the level of learning acquired in the subject by chemical engineering graduates

As mentioned above, safety is an optional course in the fourth year of the degree. The maximum number of students allowed in the subject is 20 (average group size 15.8 students), and the overall number of students per class in fourth year is 80 (average group size 79.4 students), which means that only 25% of students receive specific safety training through this subject. The rest receive safety training transversally through experimental subjects and through fourth-year compulsory subject named "Industrial Processes of Chemical Engineering" (4th year, semester A).

In order to analyze the influence that safety course has on the final level of knowledge acquired by the students in safety issues, we have represented the average of the grade obtained in a safety questionnaire given to the students in "Industrial Processes of Chemical Engineering" and the average of the final grade obtained in "Industrial Safety" taught after Industrial Processes in the B term. The results are shown in Figure 12.

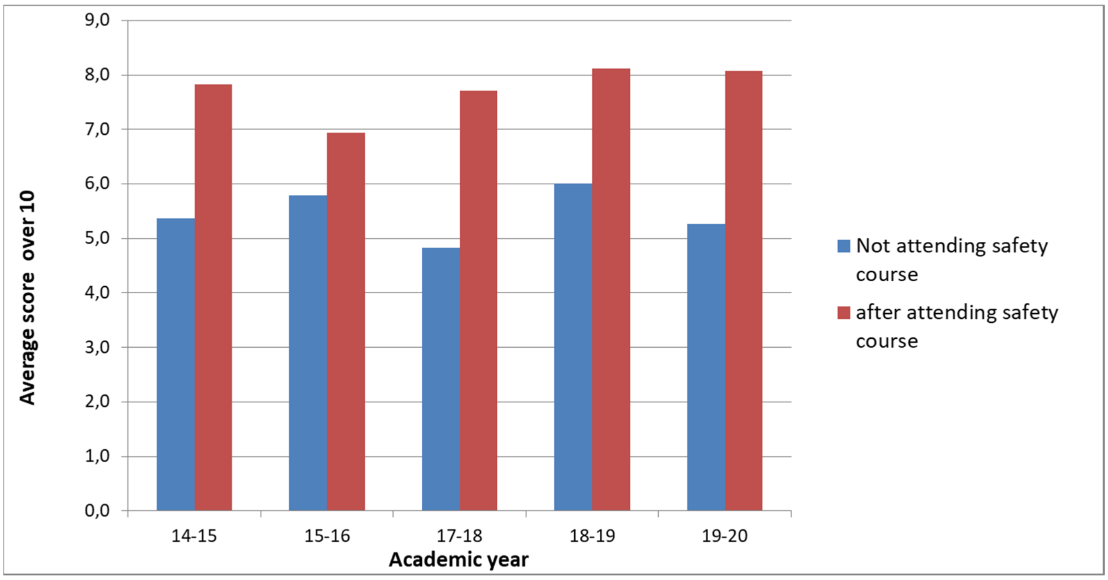

Figure 12. Comparison of the academic score in Safety of course-attending and non-attending students

As it is shown, in all the academic courses analyzed, the average grade increases after taking the "Industrial Safety" course. The average grade obtained by students not taking the optional subject is between 4.8 and 6 over 10, while for students taking "Industrial Safety", the grade is between 6.9 and 8.1 over 10. This means a gradual improvement of 43.95% in the grade obtained by students who take both subjects compared to those who only take the compulsory one.

This implies that students who take the Industrial Safety course reinforce and broaden their knowledge in this subject, reaching a higher level than students who do not take the course, which is beneficial for their training and the performance of their profession as Chemical Engineers.

5. Conclusions

Main conclusions after the analysis performed about the training of safety of the chemical engineers are:

-Training in industrial safety is essential for the development of the Chemical Engineer's profession.

-The implementation of the Bologna Process has been fundamental to include this discipline in the current study plans of Chemical Engineering in Spanish universities. It is currently a required item for the accreditation of the quality of Chemical Engineering studies at an international level.

-In the Degree of Chemical Engineering and Degree of Industrial Chemical Engineering in Spain, it is mostly an optional subject of the last year and 4.5 or 6 ECTS.

-A methodological approach that combines participative master class with a case of study or role-playing and several practical activities is useful to improve professional competences and level of learning of the students.

-Although much progress has been made, it is necessary to continue to maintain and expand training in safety, focusing on acquisition knowledge but also decision-making and "know-how" in certain circumstances.

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