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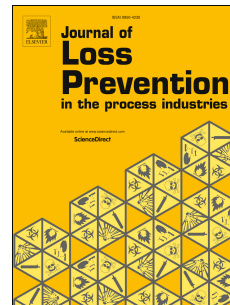
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Promoting safety teaching: an essential requirement for the chemical engineering education in the French Universities.

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Abstract

The essential contribution of education to safety and loss prevention is emphasized in this paper. It provides a review of the chemical engineering undergraduate and graduate French curriculum “Process safety”. First, the specific situation of the French chemical engineering departments is situated in the Bologna Accord. Then the three main ways to teach occupational health, safety and loss prevention in chemical engineering cursus are discussed. The principle of a layered approach is reported with the corresponding levels of outcomes, competences and safe work practice expectations.

The content of the undergraduate safety mandatory program of the French University Institutes of Technology (IUT) is indicated for the concerned chemical engineering departments.

Finally, some selected detailed lists of the different safety mandatory and elective courses concerning the corresponding French Master degrees (topics – time allocation and European Credit Transfer and accumulation System ECTS) in two Chemical Engineering Schools ENSIC Nancy and ENSIACET Toulouse are commented.

Keywords: process safety, education, chemical engineering, teaching, pedagogy.

1. Introduction

1. Introduction

Most industrial incidents or major accidents happen because the necessary knowledge and/or competence were not available at the right time in the right place. Safety expertise is of by key importance for the process industries. Acquiring, maintaining and strengthening this competence is necessary from an environmental, economic and societal point of view.

From the feedback of the occurrence pattern of the accidents, Saleh and Pendley (2012) underlined the important contribution of loss prevention education. In the same way after the dedicated two day session on process and plant safety during ECCE 8 in 2011 at Berlin, a general consensus exists about the necessity to promote a substantial increase of the relevant safety culture at university. Schmelzer et al. (2011) reported the final key messages to all stakeholders in process and plant safety. Among others, they invited to:

- Continue and strengthen existing initiatives that develop systematic approaches to create and maintain process safety competence for design and operation.
- Support the idea of a European university curriculum on process and plant safety for relevant bachelor and master degrees, preferably with EFCE taking the lead.

Since then, the respective EFCE Working Parties on Education and on Loss Prevention and Safety Promotion are intending to promote similar initiatives at European level and this resolution is in progress.

This paper provides a review of the undergraduate and graduate French curriculum “Process safety” fully updating the previous article by Perrin and Laurent (2008). Indeed, in France, the situation evolved during the decade 2008-2018 in the field of the safety teaching. The gradual generalization in University Institutes of Technology and Engineering Schools of the introduction of health and occupational safety is now effective and the transition towards the process safety is globally in progress.

First, the specific situation of the French chemical engineering departments is situated in the Bologna Accord (Molzahn, 2004, EFCE, 2010).

Then, the three main ways to teach health, safety and loss prevention in chemical engineering cursus are discussed with regard to the main existing contributions, as for example Amyotte (2013), Dee et al. (2015), CCPS (2015) and CCPS (2016). The principle of a layered approach is reported with the corresponding level of outcomes, competences and safe work practice expectations.

The content of the undergraduate safety mandatory program of the French University Institutes of Technology (IUT) is indicated for the concerned chemical engineering departments.

Finally, some selected detailed lists of the different safety mandatory and elective courses concerning the corresponding French Master degrees (topics – time allocation and European Credit Transfer and accumulation System ECTS) in two Chemical Engineering Schools ENSIC Nancy and ENSIACET Toulouse are commented.

2. Anatomy of the French chemical engineering education

The French system education presents a specific position in the panorama of the international chemical engineering universities. Figure 1 presents, at the left side, the classical European higher education system (Bologna Accord) with Bachelor, Master and Doctorate levels and, at the right side, the equivalent system of the French classical universities with the corresponding “Licence”, Master and “Doctorat”.

The *undergraduate cursus* in chemical engineering takes place during the first two years of the degree of “Licence” in the University Institutes of Technology (IUT).

Figure 2 shows the map of the 7 French chemical engineering departments existing in IUT, with the respective student flows of degree per year. After two years, the students obtain their DUT degree (Diplôme Universitaire de Technologie -Technology University Diploma). At the origin of the creation of the IUT, in the late 60s, it was planned that the majority of an undergraduate class would join the industry. Presently, 80 % of the students continue their studies in the third year of degree, then also at university in Master's degree. This raises a problem of senior technician recruitment for the industry.

The *cursus of the graduate* program is particular. After high school, most talented students follow two years of intensive courses in mathematics, physics and chemistry in the “Classes Préparatoires aux Grandes Ecoles” (CPGE). At the end, the students compete in national examinations. This allows them to enter one of the Grandes Ecoles. The French expression “Grandes Ecoles” is not easy to translate and, in the remainder of this text, it will be substituted by “Engineering Schools”. Subsequently, each French engineering school provides education during three years required to earn a French engineering degree which is higher than Bachelor and equivalent to Master.

Figure 3 illustrates the geographical situation of the full chemical engineering departments present in the French engineering schools with the specific two founding departments ENSIC Nancy and ENSIACET Toulouse. There are also some other university training including partly teaching of chemical and process engineering in their program (SFGP, 2017).

The main part of the full chemical engineering graduates are committed to the industry. Only 10 % of a promotion try to undertake a doctorate. In France, this challenge is difficult. On one hand, the difference between the starting salary of a young engineer and the grant of a PhD student is important. On the other hand, the probability to simultaneously gather a good candidate, an attractive safety subject and a reasonable grant is low.

3. Potential learning outcomes of an acceptable academic formation in process safety.

A wide range of institutions presented views on process safety competences (ABET, 2017-2018, Arezes and Swuste, 2012, CCPS, 2015, CCPS, 2016, CTI, 2016, IChemE, 2017, Pfeil et al., 2013, PROCESSNET, 2013, Schmelzer et al., 2011). All propositions insist on the importance to include safety in chemical engineering programs. But they rarely formulate potential learning outcomes, requirements and systemic competences. Furthermore, they do not suggest a convenient way to teach the recommended content.

We try to define the aim of a final acceptable safety academic formation in a chemical engineering curriculum. It is hoped that chemical engineering students graduating from a combination of first and second degrees under the Bologna process will:

(citation)

- Understand the inherent nature of safety and loss prevention, and the principal hazard sources in chemical and related processes – including flammability, explosion and toxicity (including biological hazards).
- Understand the principles of risk assessment and safety management, and be able to apply techniques for the assessment and abatement of process and product hazards.
- Understand methods of identifying process hazards (e.g. HAZOP), and assessing environmental impact.
- Be aware of specialized aspects of safety and environmental issues, such as noise, hazardous area classification, relief and blowdown...
- Have a knowledge of the local legislative framework and how it is applied to the management of safety, health and environment in practice and in the workplace, from the perspectives of all people involved, including all stakeholders, operators, designers, contractors, researchers, visitors and the public.

(end of citation)

In addition to the above requirements, underlined by IChemE, 2017, it is expected that students learning and teaching Safety, Health and Environment will be undertaken in an environment (IUT departments, French engineering schools...), where there is an obviously strong and effective safety culture and where the students will learn on the basis of examples. Normally, the achievement of these outcomes prepare undergraduates and graduates to enter a professional safety practice of chemical engineering.

4. Principles and approaches to incorporating process safety into the curriculum.

Ever since the impact of the major world industrial accidents and the subsequent Seveso rules and regulations, the French chemical engineering departments dared to include process safety into the chemical engineering curricula, although it was made with difficulties.

First, teaching safety only as rules, compliance and occupational health is insufficient. Instead, students need to learn and practice a range of safety skills in agreement with scientific fundamental knowledge, technical guidelines and good practice.

Secondly, the dedicated teaching time is constrained within an overloaded timetable. The continued pressure to include new subjects on curriculum time allocations led to excessive workloads for the students and/or a drastic content reduction for other topics.

Thirdly, experienced academic teachers able and willing to teach safety are lacking. Indeed, young teachers are not encouraged at the beginning of their career to devote time to prepare safety lessons, lectures and tutorials. The progress and the promotion of the teachers are examined and decided by the National Committee of Universities (CNU). This authority is divided into sections, each of them being defined by a scientific topic of Auguste Comte's vertical classification typically mathematics, physics, chemistry, biology, sociology... It is thus very difficult for the topic of process safety, by nature a transverse subject of interdisciplinary integration, to be easily recognized or welcome by a CNU section. The evolution of the situation however progresses because the section entitled "Energetics and process engineering" would accept the individual applicant files dealing with process safety. At least, the link between industry and university is a key factor for achieving high performances in process safety (Benintendi, 2016). Unfortunately, in France, the support of the industry to participate as an actor in safety teaching in university departments is insufficient. For example, it is difficult to obtain the temporary help of a process safety expert from industry to deliver a formal lecture on a specific safety topic. It is almost impossible to consider the recruitment of a part-time professor based in industry to promote the safety synergy between himself and the team of academic teachers of the department.

It is nevertheless possible to define the principle of an approach to including safety into a chemical engineering curriculum. Gillett (2001) and Azevedo (2001) recommended a general approach to teach chemical engineering. Each subject was considered in elements that reflected three stages of learning. The first stage provides a superficial awareness. The second stage delivers an increasing appreciation sufficient to work with experts. The third stage corresponds to the level of full understanding and expertise. We propose to transpose the same process to teach safety. Table 1 shows an example of application for the subject "Vapour Cloud Explosion" (VCE). This layered approach can be applied and expanded whatever the level of education.

5. How to teach process safety in chemical engineering course?

The literature globally reports three approaches to include process safety into the chemical engineering curriculum. Pintar et al. (1998), Pintar (1999) and Dee et al. (2015) seriously discussed the variety of strategies to introduce process safety into chemical engineering curriculum.

The question is whether the safety and hazards aspects should be:

- Included as part of all chemical engineering existing courses (Amyotte, 2013, Benintendi, 2016, Dee et al., 2015, Hill, 2016, Leveneur et al., 2016, Pintar et al., 1998, Pintar, 1999, Shallcross, 2013, Shallcross, 2014).
- Taught as a separate full course on process safety (Benintendi, 2016, Dee et al., 2015, Gabas, 2010, Krause, 2016, Lemkowitz, 1992, Meyer, 2017, Perrin and Laurent, 2008, Pintar, 1999, Pitt, 2012, Schmidt, 2013).
- Integrated simultaneously in a separate process safety course and as a part into an existing chemical engineering course (Benintendi, 2016, Dee et al., 2015, Lemkowitz, 1992, Mannan et al., 1999, Véchet et al., 2014).

The final choice depends on the teaching philosophy of each department, but the following points should be considered.

The first way, including safety as part of all chemical engineering existing courses, presents an advantage as it can be coordinated with the rest of course material. Safety can serve as an integrating factor in a lecture. However, the major disadvantage is the lack of focus on process safety. This way of integration could be continual reinforcement over a two or three year periods of curriculum in France. Nevertheless, problems occur in dealing only with other subjects. It cannot be expected that the academic staff across the whole discipline will present the necessary interest, knowledge and experience. Moreover, such a treatment should be based on unifying systemic principles (Perrin and Laurent, 2008 – Gabas, 2010). At present, this way is ever in France the most difficult to implement because of the lack of faculty members with sufficient background and interest to teach such a material.

These latter arguments are important and the present tendency in France is to promote the second way with a separate course in safety. In this strategy based on teaching a separate full course, the previous drawbacks would disappear. The course would be more consistent and could better aggregate other knowledges. We believe that the main advantage of a separate course is that such a course can concentrate on the subject and especially present a systemic approach.

The last strategy is a combination of both previous ways. Benintendi (2016) reported that the process safety concepts should be provided and integrated as much as possible within the basic subjects of chemical engineering. He proposed a typical table identifying some respective links between safety and chemical engineering subjects such as reactor runaway and chemical reaction engineering, explosion energy/ adiabatic flame and thermodynamics...

6. French safety undergraduate outlook

Principle-based safety education for undergraduates needs to start at the very beginning of chemical engineering, explaining the “why” of safety. Many undergraduates need to begin learning the first principles of chemical engineering and lab and pilot plant safety.

Traditionally, the content tended to cover aspects such as legal requirements and personal safety (for example, personal protective equipment). The previously presented layered approach of three stages of learning has been developed for first-year, second-year and advanced undergraduates. In France, the content of the corresponding mandatory program for the seven chemical engineering departments is defined by the National Educational Committee (CPN) of University Institute of Technology under the supervision of the Ministry of the Higher Education and Research.

Table 2 summarizes the undergraduate safety curricula mixing elementary notions, legal requirements and some engineering aspects with the corresponding allocated time and ECTS. Written exercises and/or on line Multiple Choice Questions are given in exams.

7. French safety graduate view

The teaching master program is based upon the decisions of the Bologna process and the recommendations of EFCE for education of chemical engineers.

The compulsory and elective programs for the chemical engineering departments of ENSIACET Toulouse and ENSIC Nancy should be accredited, according to its recommendations for the process safety education, by the Commission du Titre d'Ingénieurs Committee of Engineering Qualifications (CTI) of the Ministry of the Higher Education and Research and according to the agreement of the industrial members of the board of the departments.

The opportunity to obtain the accreditation of the IChemE is also convenient to respect its appropriate standards. In 2017, ENSIC Nancy is the only French department of chemical engineering accredited by IChemE.

Due to the time allowed (and consequently the low ECTS score), we should concentrate on a limited set of topics rather than make the mistake of overloading the students with an excessive content.

Table 3 recapitulates the global allotment of process safety mandatory and elective courses in the French chemical engineering curricula for the Nancy and Toulouse departments with the corresponding semesters, timetables and ECTS. Some comments are useful to complete the interpretation of the contents of this table.

The time associated with the presence of the students in the compulsory courses results from a compromise with the other contents of the whole curriculum of the chemical engineering departments. In addition, the personal working time of every student should be used to assimilate and to intensify the bases of process safety knowledge. Provided that each graduate student attended effectively the mandatory courses, at best it would be considered that his basic knowledge in process safety allows him to discuss with the safety experts. Next, it is recommended to follow and assimilate the additional elective courses to be able to correctly apply the basic safety principles to process and plant safety.

During the semester 8 the chemical engineering graduate students are required to achieve a plant design project. Each report should include one chapter dedicated to the process safety assessment of the proposed design.

Besides, in semester 10, a compulsory industrial training course of 6 months in collaboration with process safety teams of a company is also a beneficial skill to test and improve the application of the acquired knowledge.

During their curriculum, the students can obtain the certificate of first-aid worker. For example, the course related to this possible certificate validation is fully integrated at ENSIACET Toulouse. In the same manner, the students are encouraged to prepare the double certification for the external contractors intervening on Seveso chemical sites (level operator and level engineer) validated by the French Chemical Industries Association (UIC) in compliance with the International Labour Organization ILO-OSH recommendations.

In 2017, ENSIC Nancy obtained the French label “CNES & ST” (Conseil National pour l’Enseignement de la Santé et Sécurité au Travail – National Committee for Education in Occupational Health and Safety at Workplace). This label is based on the implementation of a key competency standard with respect of two agreement charts, the one with CNAMTS and CTI (Commission des Titres d’Ingénieurs – Committee of Engineering Qualifications), the other one with CNAMTS, INRS (Institut National de Recherche et Sécurité – National Institute of Research and Safety) and a network of the French Engineering Schools.

The assessment of safety education is absolutely necessary. It is a process that identifies, collects and prepares data to evaluate the attainment of the student outcomes and the program educational objectives. Effective assessment uses relevant direct, indirect, quantitative measures as appropriate to the exposed goal. In France, the panoply of used practices in the chemical engineering departments are: standard written exam paper, open book exam, Multiple-Choice Questionnaire (MCQ), oral presentation, project, writing of reports, rehearsal of a tutorial, note of an industrial plant visit, asking questions in classes or during projects... A unique approach of qualitative or quantitative metrics to process safety education is not

presently applied in France. Every chemical engineering department is globally responsible for its educational autonomy. A solution could be to appreciate the feedback of the applications of the criteria recommended by ABET in USA (ABET, 2017-2018, Michelson et al., 2001).

The next successive tables regrouped in the appendix illustrate some selected examples of the safety academic units:

- a mandatory initiation course at ENSIC Nancy (Table 4),
- a mandatory core course at ENSIC Nancy (Table 5),
- another mandatory course at ENSIACET Toulouse (Table 6),
- an overview of the QSE elective option at ENSIACET Toulouse (Table 7).

8. Inventory of the recommended used teaching aids

For the particular subjects of safety engineering, the departments arrange several available teaching aids from the open literature. According to these aids, each teacher has the educational opportunity to prepare his lectures and tutorials to suit the concerned subject topic, the level of learning and the teaching environment. The main recommended used teaching aids are:

- Books (Crowl and Louvar, 2002, Kletz, 1993, 2001, 2009, Kletz and Amyotte, 2010, Laurent, 2011, Mannan, 2012, TNO The coloured books, Meyer and Reniers, 2016...).
- Reports and notes (CCPS AIChE, Collection of safety guidelines, INERIS Omega reports, HSL reports, SACHE online courses, Crawley, 2014...).
- Database (Aria, Facts, Mars...).
- Films and videos (CSB US Chemical Safety Board, INERIS, INRS...).
- Cases studies (Mannan, 2012, Shallcross, 2013, Loss Prevention Bulletin...).
- Automatic teaching devices (Cameo, Aloha, Phast, Hazid & Hazop softwares...)

9. Conclusion

The education of chemical engineers with respect to the principles of safety should be a priority in France. Although the integration of safety with chemical engineering education is important, it has not been sufficiently widespread. It has been noted that some important barriers to improve the education of safety still significantly slow down its promotion and acceptance in the French universities.

The French chemical engineering departments must adjust and continue to modify their approach to safety education. Perhaps, a better strategy would be the third mentioned way consisting to include progressively and simultaneously a comprehensive exposure to chemical engineering core courses including safety applied problems as well as specific process safety courses. For example, at INSA Rouen (F), Leveneur et al. (2016) presented a pedagogic approach in a classical chemical engineering course showing the coupling of mass and energy balances in chemical reactors for a better understanding of thermal safety and runaway. The transposition of some existing postgraduate ways, such as, for example, in TU Delft (Reniers et al., 2017, Swuste and Sillene, 2018) and in Mines Paris Tech (Wybo and Van Wassenhove, 2016), could be another opportunity to improve the contents of the safety engineering French education.

In summary, the education in safety is a difficult mission and a hard challenge that implies an important educational commitment. As the academic programs of the university departments are ever overloaded, the safety teaching to the undergraduate and graduate chemical

engineering students has to concentrate preferentially on the basic process safety topics, to avoid the scattering of subjects.

At last, let us share and agree with the words of Asezes and Swuste (2012) “An academic qualification is regarded essential since those specialists must be capable to address new problems by applying knowledge and skills to situations not previously encountered”.

Warning

The content of this paper was initially presented during WCCE 10 Barcelona (1-5 October 2017) in the Joint Event “Process Safety Symposium” session Education.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily represent those of others.

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TABLE CAPTIONS

Table 1 - Example of the steps for teaching the subject “Vapour Cloud Explosion” (VCE).

Table 2 – Safety curricula in French chemical engineering departments IUT (undergraduate).

Table 3 - Allotment of process safety mandatory and elective courses curricula in the chemical engineering departments – French engineering schools (graduate)

Table 4 – Mandatory initiation course at ENSIC Nancy – Hygiene, Health and Safety at Work (Semester 5 – 6 hr – ECTS 0.5)

Table 5 – Mandatory core course at ENSIC Nancy – Safety and sustainable development (Semester 7 – 24 hr – ECTS 1.5)

Table 6 – Mandatory course at ENSIACET Toulouse – Process safety - Occupational Safety and Health (Semester 7 – 20 hr – ECTS 1)

Table 7 – Overview of the QSE elective option at ENSIACET Toulouse (3rd year)

Table 1

What subject?	Stage	Level	What to teach?	When to teach?
VCE	1 Awareness	Beginner	Gas phase deflagration and detonation Human and equipment blast effects	at any time
VCE	2 Appreciation	Practical	Positive and negative pressure and impulse versus time TNT and MEM models	after awareness
VCE	3 In depth knowledge	Expert	Explosion prevention, mitigation and suppression Quantification: probability of an explosion event	after appreciation

Table 2

Semester	Topic	Volume	ECTS
1	Initiation course: risk – hazard - metrics Safety awareness – Safety charter	8 hr Lecture 4 hr Tutorial	0.2
2	Rules and international regulations REACH – GHS – Seveso...	4 hr Lecture	2
4	Process safety – hazard identification Risk analysis methods	10 hr Lecture 12 hr Tutorial	1.5

Table 3

Semester	ENSIC NANCY	ENSIACET TOULOUSE
5	* Mandatory course I Lectures 6 hr ECTS 0.5	*Mandatory course I Lectures 14 hr 40 ECTS
6	*Mandatory course II Lectures 6 hr ECTS 0.5 * Elective course I Lectures 12 hr ECTS 1	
7	*Mandatory course III Lectures 18 hr ECTS 1.5 Tutorials 6 hr	* Mandatory course II Lectures 22 hr ECTS 1
8	*Elective course ECTS 3 Lectures 16 hr Tutorials 12 hr *Core course ECTS 4 Lectures 24 hr Tutorials 12 hr *Industrial project ECTS 6	
9	*Research and development project ECTS 10	*Elective course ECTS 18 Lectures 234 hr *Industrial project ECTS 9
10	*Industrial training course 6 months ECTS 10	*Industrial training course 6 months ECTS 20

Table 4

Item	Topics
1	Introduction to Health and Safety at work.
2	The human, social, economic and legal aspects of Occupational Health and Safety.
3	The mechanisms and the origins of work accidents.
4	Preparation for the industrial internship and future jobs. Discovering the world business by participating in an employment fair organized by the Management department and Industrial Relations department. Students discover the world of business through panels and meetings with many industrialists.
Exam	MCQ examination

Table 5

Item	Topics
1	Design and inherent safety
2	Basic knowledges: fire, gas, vapour and dust explosions
3	BLEVE – Rollover
4	Dispersion – Thermal runaway
5	Risk analysis methods: PRA – Hazop – Fault tree...
6	Life cycle analysis – Product and process management
Exam	Open book written examination and project

Table 6

Section	Topics
Process safety	Regulatory requirements at the French and European level Risk assessment methods (Hazid – Hazop – Bowtie...) Industrial management principles Practical exercises (Written exam)
Occupational safety and health	Occupational risk evaluation method Practical exercises (Oral exam)

Table 7

Academic units	Subjects	Volume (hr)	ECTS
UE 2	Occupational safety and health	24	2
UE 3	Management systems	20	2
UE 4	Clean and safe process engineering	96	6
UE 5	Prevention of occupational risks	37	4
UE 6	Advanced QSE management systems	57	4

FIGURE CAPTIONS

Figure 1 – Situation of the French chemical engineering departments in the Bologna Accord.

Figure 2 – Departments of chemical engineering – University Institutes of Technology (IUT)
Degrees per year: **O = 100 (red)** - **⌘ = 50 (green)** - **• = 30 (black)**
Adapted from SFGP (2017)

Figure 3 – French chemical engineering schools - Master level
Acronym of each engineering school with the corresponding Master degrees per year. Adapted from SFGP (2017)

Figure 1

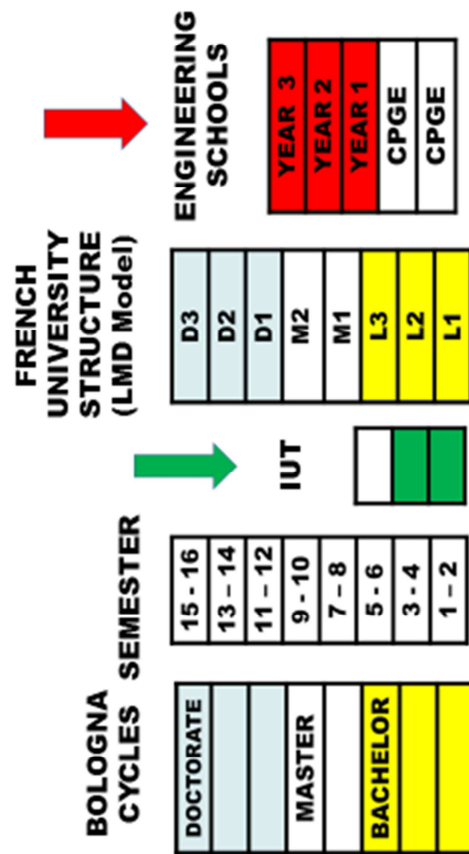
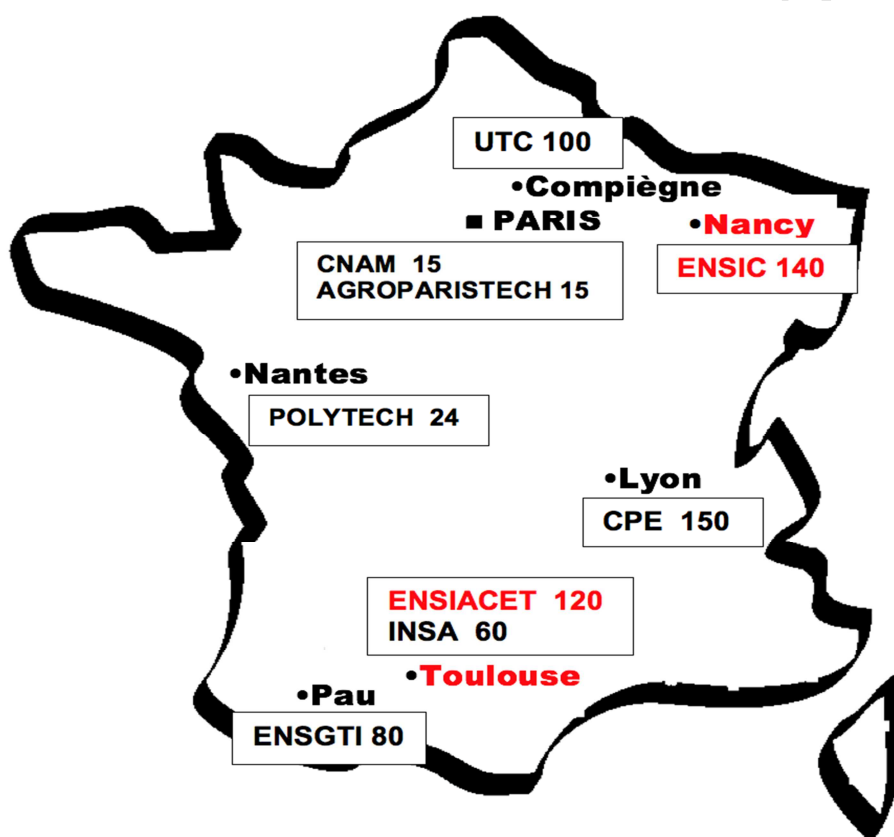


Figure 2



Figure 3



ACCEPTED MANUSCRIPT

Highlights

- Safety should be mandatory in education.
- How to teach safety in chemical engineering?
- Safety learning outcomes, requirements and systemic competences.
- Overview of the French undergraduate and graduate curricula.