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Training future engineers to be committed to safety

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ABSTRACT
History has shown at multiple occasions that major incidents in the process industry have the potential to affect the world in different aspects: loss of life and economic losses and environmental disasters. Can the occurrence of major preventable incidents be seriously decreased by investing in better education and research in process safety? This paper will share ideas on how to convey safety as a value to engineering students. Emphasis with be put on making them participants and actors of process safety related activities at early stages of their education in order to work at the development of their safety culture well before the start of their professional life. These activities include their involvement in current research, laboratory activities using specific equipment, long term projects on the study of incident that defined process safety. The integration of process safety principles in other regular engineering courses will also be discussed.

Keywords: process safety, safety culture, incidents memory, active learning, transmission of values

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1. WHY TEACHING PROCESS SAFETY?

Flixborough (1974), Seveso (1976), Bhopal (1984), Chernobyl (1986), Piper Alpha (1988), Buncefield (2005), Texas City (2005), Deepwater Horizon (2010), Fukushima (2011), Punto Fijo Venezuela (2012). These are some of the marking events in the history of industry that have shown its potential to affect the world in different aspects. Major industrial incident have indeed the potential for losses of life as well as economic and environmental losses. The U.S. Environmental Protection Agency illustrated this point by reporting that, between 1997 and 2001, 1970 industrial incidents in the U.S. chemical industry that resulted in approximately 2000 deaths and injuries, and in more than $1 billion in property damage (not including interruption of the production and other costs associated to the incident) and affected communities with over 200,000 people who had to be evacuated.[1]

Actually, industrial incidents (including minor events) happen more often than reported by the media. These work related incidents may result in work absences, minor to severe injuries, fatalities, business interruptions, evacuation of communities, and environmental damages with the associated economic consequences. According to the U.S. Bureau of Labour Statistics, 908,300 incident cases involved days away from work, and 4,609 fatalities were reported in the only in 2011. The Health and Safety Executive reported that for the year 2011/2012, in the UK, 1.1 million workers suffered from work-related illnesses, 173 workers were killed at work and 27 million working days were lost due to work-related illness and workplace injury. In addition they estimated that workplace injuries and ill health (excluding cancer) were costing society an estimated £13.4 billion in 2010/11.

Process safety is of critical importance to ensure the sustainability of an industrial activity. Unfortunately the importance of process safety has always been promoted only after high-visibility industrial incidents, characterized by dramatic casualty tolls, significant environmental damages and financial losses. As described by the Mary Kay O'Connor Process Safety Center in its process safety research agenda for the 21st century, the sudden awareness tends to be forgotten moths after the disaster and complacency comes back as well as disturbing school of thought such as: *"if nothing bad happens, it is because there are no hazards, and if there are no hazards, then there is no need to take preventive measures"*.[2]

Over the years the study of industrial incidents showed particular patterns, which suggested that education plays an important role in contributing to their prevention.[3] It is therefore legitimate to question ourselves on our understanding of the ways to prevent and mitigate such major incidents and how to efficiently teach them to the upcoming generation of engineers.

A survey performed by the Mary Kay O'Connor Process Safety Center in 2006 revealed that out of approximately 150 chemical engineering departments in the United States, only 11.2% of responders had a compulsory, core course in process safety.[2] These results are somewhat alarming. Still nowadays, there is a systematic negative perception or misconception regarding process safety research and development within academic circles. There still is a general misunderstanding of the meaning of *process safety*, too often confused with a limited part of *occupational safety* and associated with the image of hard hats, lab coats or goggles. The academic community does not yet fully appreciate the importance of safety and in particular process safety.[2]

2. AN INTERESTING CASE STUDY: THE T2 LABORATORY INCIDENT, JACKSONVILLE, FLORIDA, U.S., 2009

In 2002, the U.S. Chemical Safety and Hazard Investigation Board (CSB) published a comprehensive report on the rate, types, and causes of incidents involving reactive chemicals.[4] Among other key findings, the CSB reported that 167 incidents of this type happened between 1980 and 2001, resulting in 108 fatalities, hundreds of injuries and serious public impact. The report also documented that 35% of them were due to runaway reactions. The major conclusions of this report were that incidents involving reactive chemicals were a serious problem in the U.S. and that both management system and regulatory improvements were needed.

Five year after the publication of this report, the CSB had to investigate the T2 laboratory incident, which was qualified by the Chairman of the CSB at the time, Mr. John Bresland, as "one of the largest chemical accidents the CSB has investigated".[5] In this incident four employees were killed and other four were injured by an explosion and subsequent fire in 2007 in Jacksonville, Florida.
The explosion also caused 28 persons to be injured offsite in the plant surrounding due to the debris scattered by the blast. Debris from the reactor in which the incident took place was found up to one mile away from the plant.

The CSB found that the incident was due to an exothermic runaway reaction during a batch producing MethylCyclopentadienyl Manganese Tricarbonyl (MCMT). The runaway led to an uncontrolled exponential temperature and pressure increase in the reactor vessel. The reactor vessel burst and released its contents, which ignited, causing an explosion equivalent to 1400 lbs. of TNT. This sequence of event took place in 10 minutes. The CBS listed the following technical root and contributing causes: (1) T2 did not recognize the runaway reaction hazard associated with their process; (2) The cooling system was susceptible to failures as no redundant design was present; and, (3) The reactor relief was incapable to reliving the pressure from a runaway reaction of the process. The CSB also pointed out that although both the owners had a bachelor respectively in chemical engineering and in chemistry, none of them was aware of chemical reaction hazards.

One of the major results of the investigation were recommendations that CBS made to the American Institute of Chemical Engineers (AIChE) and the Accreditation Board for Engineers and Technology (ABET) to "add reactive hazard awareness to baccalaureate chemical engineering curricula requirements, and inform all student members about the process safety Certificate Program and encourage program participation".

3. EFFORTS TOWARDS THE TEACHING OF PROCESS SAFETY

ABET's general criteria for baccalaureate level programs has been including already health and safety for many years under the Criterion 3 – outcome (c). It states that the student must develop the "*ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability*".

ABET in its new guidance (2011) is now requiring analysis and control of process hazards to be included in the program-specific criteria for Chemical Engineering as follows:

> "*The curriculum must provide a thorough grounding in the basic sciences including chemistry, physics, and/or biology, with some content at an advanced level, as appropriate to the objectives of the program. The curriculum must include the engineering application of these basic sciences to the design, analysis, and control of chemical, physical, and/or biological processes, including the hazards associated with these processes*".

This ABET new guidance and requirements are expected to impact chemical engineering departments throughout the United States (and other ABET accredited institutions) from 2012 onwards.[2]

In 2010, the Safety and Chemical Engineering Education (SAChE) program,[6] which is a cooperative effort between the Center for Chemical Process Safety (CCPS) and engineering schools in the U.S., wrote some recommendations on how chemical engineering programs can implement ABET requirements. This document particularly stressed the importance for the student to understand the technical aspects of process safety related to hazard identification and risk assessments and reduction, safety management systems and regulatory requirements. A key recommendation was for the student to understand the importance of process safety and the commitment required. This particular aspect can be overlooked if one tends to restrict the teaching of process safety to the simple application of engineering principles to solve engineering problems in the safety area. Teaching of process safety must contribute to transmit a value to the future engineers.

To help complying with these new ABET requirements it is important to be aware of the fact that the SAChE program has been proactive for many years in the area of process safety teaching via the production of teaching resources for educators on process Safety.[7] Since 1985 the SAChE program has developed and reviewed teaching material (53 publications) aimed at safer operations that can be used by students in different field of engineering and science.

4. TEXAS A&M AT QATAR'S APPROACH TO PROCESS SAFETY EDUCATION

Texas A&M University has taught process safety engineering as a core mandatory course to its senior chemical engineering undergraduate student for many years. A process safety engineering course is also taught as an elective to the student of the Graduate Program in Chemical Engineering. Texas A&M University at Qatar (TAMU-Qatar) has made a substantial efforts and investments to teach process safety and loss prevention to its students in the past five years, which are highlighted below. The focus has been on the development of teaching programs, selected key activities, and development of key equipment to improve the quality of the teaching and transmit safety and process safety as a value to the students. These efforts can be subcategorized as follows.

4.1. Formal academic approach

In 1991, Marshall[8] wrote that to qualify as a discipline process safety should be acknowledged by academia, recognized as relevant by students, intellectually demanding, have defined principles, be subjected to mathematical analysis, be taught by specialists, have its own textbooks, be compulsory and examined formally.

These principles are followed for the development of the process safety engineering courses at TAMU-Qatar. Figure 1 shows the content of the process safety engineering course. All the notions and principles covered in the course are introduced by a case study or a major incident. For example, the concept of Inherent Safety is introduced by the study of the Flixborough incident in 1974 in the UK, through the eyes of Trevor Kletz, one of the fathers of process safety. The principles of toxicology are covered in relation with the Bhopal incident with the disastrous consequences associated. The CSB produced numerous 3D animations to help in this area.[9] When possible the names of the victims are given. For example, the part of the course on vapor cloud explosion are related to the name of Mary Kay O'Connor, an operations superintendent killed in an explosion on October 23, 1989 at the Phillips 66 Complex in Pasadena, TX. The student need to know that she graduated from the University of Missouri-Columbia with a degree in Chemical Engineering and received a MBA from the University of Houston-Clear Lake and died at the age of 34. This approach is extremely important as it leads the student: (1) to recognize the importance of safety, (2) to really understand that safety must be a value (and not only a priority), (3) to develop a safety awareness and a safety culture based on the knowledge on the history of incidents and the resulting key lessons, (4) to realize that safety related engineering decisions can have serious consequences on people and their families (onsite and offsite), the business and the environment, and (5) to understand the importance of a personal and corporate commitment to safety.

4.2. Learning through case study

Trevor Kletz has for many years conveyed to the industry the importance of incident investigation, learning from the mistakes and developing a corporate memory.[10] As a part of the process safety

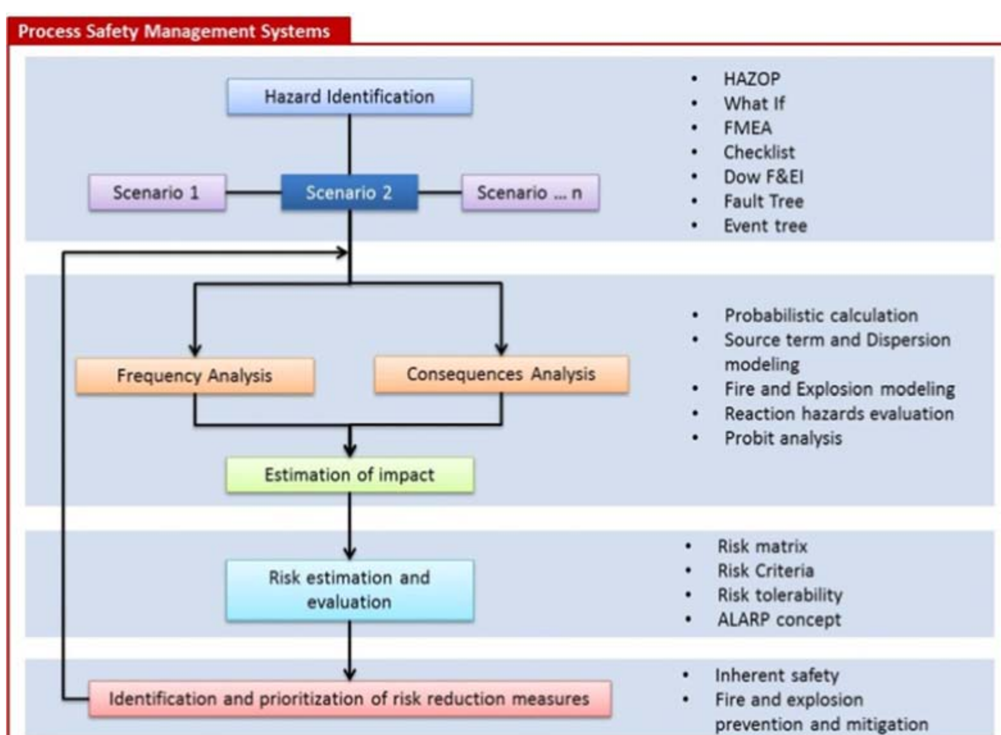

Figure 1. Process safety engineering course contents.

engineering course, the students are asked to investigate a significant industrial disaster. The work is performed in groups of two to three students, each group being led by a team leader responsible for overseeing the overall project and ensuring that the outcomes follows the highest standards. The objectives of the research project are the following:

- Research the details of this accident.
- Explain the phenomena that caused the destruction of the facilities and loss of lives and injuries.
- Research the circumstances surrounding the incident.
- Research the consequences of the accident in terms of fatalities/injuries, economic losses and impact on the public/local community/the company itself and the impact in industry practices and regulations.
- Research a history of any similar accidents and establish the lessons learnt from these incidents.
- Focus on a particular point/aspect of the incident that caught their attention (which allows the students to express a personal opinion on the topic studied).

A detailed report and a 25 minutes presentation given to the class are expected at the end of the semester. Attendance to the presentation sessions is mandatory as each presentation is followed by a discussion where the class (not only the teacher) can challenge the students on their investigation, recommendations and conclusions.

Table 1 gives the list of the incidents investigated by process safety engineering student over the past two years.

4.3. Learning through experimental work

Previous research on the theory of student learning suggested that students retain 90% of what they see, hear, say and do. This should be kept in mind particularly when teaching process safety. One tends to really believe in the reality or the seriousness of a particular hazard only after having experienced it in diverse way (observation or personal experience). For example, very few people realize that divided material (dust, powder) manufactured by the food industry and present in everybody's kitchen drawer have been at the origin of severe explosion in the industry. This lack of awareness is immediately corrected when one sees a dust explosion for the first time.

Based on the above reasoning, TAMU-Qatar via Qatar Foundation initiatives has significantly invested in the development of a process safety laboratory equipped with key process safety related experimental facilities.

Table 1. Incidents studied by Chemical Engineering students at Texas A&M at Qatar

Name	City	Country	Date
Seveso Incident	Seveso	Italy	1976
PEMEX LPG Terminal	Mexico	Mexico	1984
Bhopal disaster	Bhopal	India	1984
Chernobyl disaster	Chernobyl	Ukraine	1986
Piper Alpha	N/A – offshore	UK	1988
Phillips 66 Explosion	Pasadena	U.S.	1989
AZF factory explosion	Toulouse	France	2001
Buncefield Explosion	Buncefield	UK	2005
BP Texas City	Texas City	US	2005
Imperial Sugar Explosion	Port Wentworth	US	2008
BP Deepwater Horizon	N/A – offshore	US	2010
Fukushima Daiichi nuclear disaster	Fukushima	Japan	2011

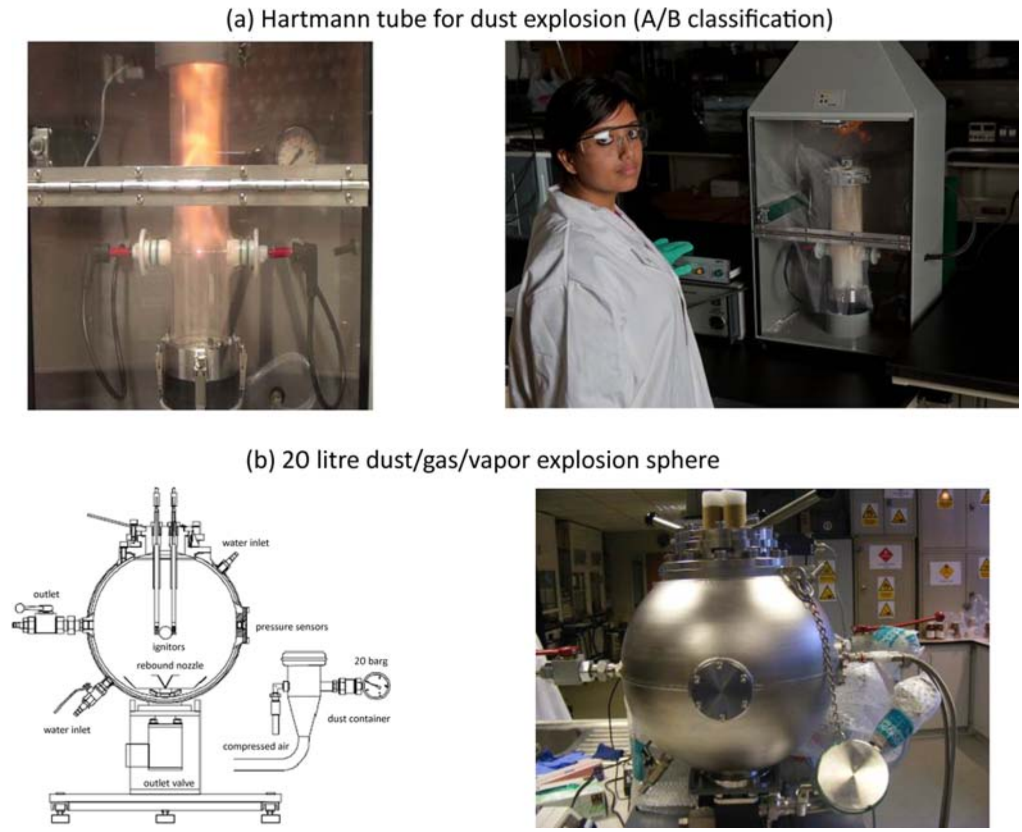

Figure 2. Equipment for dust/gas/vapor explosion related student projects.

- A **Modified Hartmann Tube** (Figure 2a), designed to qualitatively pre-test the explosion behavior of a dust/air mixture, was purchased in 2011. It is composed of a vertical Pyrex glass tube (1.2-liter) in which fine powder/dust products are dispersed by an air blow. The tube is equipped with electrodes that can generate a spark of known energy and subsequently ignite the sample.
- A **20 litre sphere** (Figure 2b) was purchased in 2012 (currently boing commissioned) to quantitatively characterize dust/vapor explosions. This apparatus allows the dispersion of a flammable dust/vapor material a 20 litre explosion chamber via a special distribution system, in which the formed atmosphere is ignited. The pressure and temperature of the explosion is recorded as a function of time and the severity of the explosion therefore quantified.
- Four calorimeters used for the characterization of the hazardous properties of reactive chemicals (**Power Compensation Differential Scanning Calorimetry** – Figure 3a), the thermal hazards from a reactive mixture in plant operating conditions (**SIMULAR Reaction calorimeter** – Figure 3b) and in thermal runaway conditions (**Phitec I**, Figure 3c and **Phitec II**, Figure 3d adiabatic calorimeters) have been purchased.

Projects involving the use of these cutting experimental facilities have been developed. These projects include the performance of a risk assessment for the planned experimental work.

For example, one project was proposed and performed where the student were asked to determine a suitable emergency relief system (ERS) dimension necessary to protect a multipurpose vessel against the consequences the runaway reaction of different reactive mixtures. This study involved a full literature study of the ERS design methodology for reactive mixtures and an extensive experimental work to obtain design data from the adiabatic calorimeters cited above. The student can then appreciate the amount of experimental work involved in such activities. The student has also to apply the engineering principles to take a design decision that could potentially result in disastrous if not performed properly.

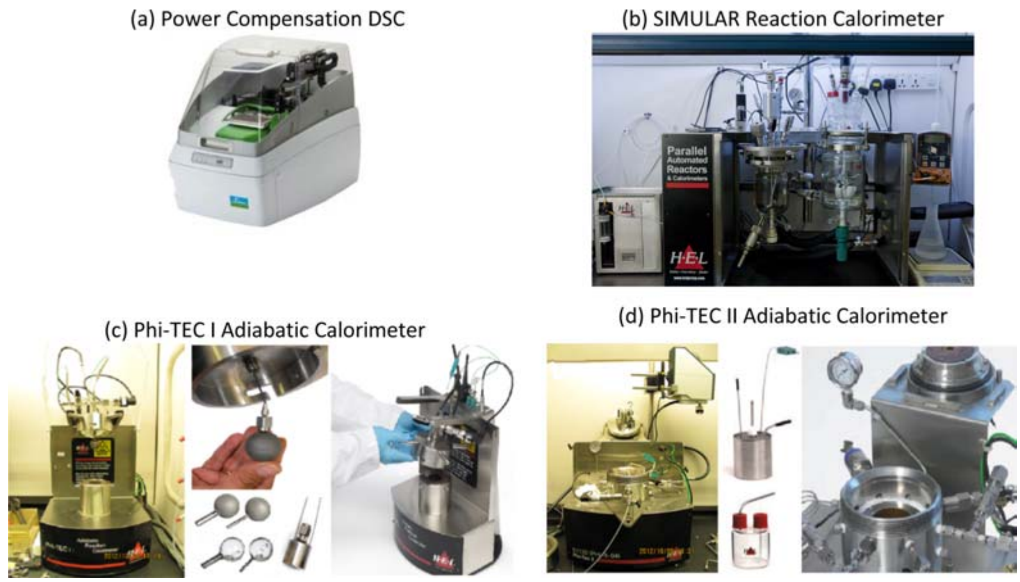

Figure 3. Calorimetric facilities for chemical reaction hazards related student projects.

Another example of project was the study of the imperial sugar explosion in Port Wentworth, U.S., 2008. The students were asked to perform the research work as described above in 4.2. In addition they were asked to run a set of experiments a with the Hartmann tube to qualitatively pre-test the explosion behavior of powders commonly used in food industry and present in their kitchen. Experiments were performed with icing sugar, coffee, cocoa and flour.

Another way of promoting safety culture has been the involvement of undergraduate students in the process safety research activities developed at by involving students in our research projects. All year long, three to four undergraduate students are involved in the major LNG safety and the chemical reaction hazards research programs at the university. Within the framework of these research activities, the undergraduate students are invited to present their work on a poster for the Annual Qatar Process Safety Symposium, where they get an exposure to process safety professionals.

5. CONCLUSIONS AND RECOMMENDATIONS

Texas A&M at Qatar has made significant worked on the past years to increase the quality of the process safety teaching in the chemical engineering program. Teaching material (and philosophy) supported by selected key activities (major incident study projects) were developed. In addition, major financial investment in key process safety related equipment was made to support the learning of process safety through experimental activities.

These efforts will hopefully improve the quality of the teaching and contribute to transmit Safety and process safety as a value to the students. So far encouraging results and feedback were obtained, as expressed by the students from end of the semester student surveys which highlighted that the students:

- Acknowledged the fact that taking a process safety course was mind opening.
- Understood the importance of safety culture along the technical aspects of the course.
- Highlighted the value of the project on a major incident in improving their understanding of the personal and organizational commitment required for safety.
- Highlighted the value of experimental work in improving their understanding, seriousness and awareness of reactive chemicals and explosion hazards.
- Appreciated the multidisciplinary nature of process safety which requires the understanding of major key engineering concepts and principles, as opposed to the widespread misconception in academic circles and students in particular of process safety being an "easy subject". This point was highlighted in 1997 by Hale et al who explained the importance of equipping graduates with "*a broader perspective on their disciplines, in order to be able to look beyond the technical issues and integrate multidisciplinary safety considerations into their decision making*"[11].

The following ideas could be tested to go further and improve the quality of process safety teaching:

Integration of process safety concepts in regular courses: The questions of teaching safety as a separate full course or as integrated part in conventional chemical engineering core courses. Some authors agree with the idea of having a standalone course[3,12,13] while others tend to agree to teach process safety across the chemical engineering curriculum.[14] We think that integrating process safety principles to conventional chemical engineering core courses will certainly contribute to raise the student awareness of the subject. For example, the principles of runaway reaction and calorimetry could be developed under a reaction engineering course, and source term and vapor dispersion modeling could be a part a fluid dynamic course. Numerous similar examples can be found in the book *Lee's Loss Prevention in the Process Industries*.[15] This would involve efforts and coordination at a program level and could indeed be beneficial. However, we think that it is important to also have a stand-alone course dedicated to process safety as this is where a global overview integrating all complex aspects and sub-disciplines of safety (including human aspects) can be presented. A stand-alone course also gives the opportunity to develop a safety culture based on the study of previous incidents via diverse research project work

Exposure to industry: We believe that promoting the exposure of students to the process safety professionals in the industry will contribute to their education and awareness. With this idea, we have invited the undergraduate students involved in process safety research to present their work on a poster for the Annual Qatar Process Safety Symposium. This revealed to create opportunity for professional and student to interact and exchange ideas.

This exposure could also be via the increase of the participation of process safety specialist from the industry in the delivery of the formal courses in the safety courses on specific topics.

The chemical engineering senior undergraduate students are required to perform a plant design project. This project involves the assessment of the safety of the proposed design. We believe that much more emphasis must be put on the safety parts of such project, maybe with the collaboration of process safety professional playing the role of consultants.

The industry/academia collaboration toward the improvement of process safety teaching could also be improved by setting up agreements to welcome student in process safety teams of companies for internships on a defined process safety topic.

Investing in process safety Research: The funding of process safety related research project (from the Qatar local industry, research funding agency and authorities) in which undergraduate students can be involved at the early stages of their engineering education will strongly encourage the training of new generations of engineers committed to safety.

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