



An educational module on fire and explosion safety for undergraduate chemical engineering students

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Abstract

Incidents, such as the fire that occurred between December 21st and 23rd 2022 at the fuel tank storage facility in Barranquilla, remind Colombian industries of the risk of fires. Chemical engineers are responsible for designs and technologies that prevent fires and explosions. Yet, fire and explosion safety is not a subject that is explicitly addressed in the Chemical Engineering curriculum. This study describes an educational module that fosters in Chemical Engineering undergraduate students competencies relevant in fire safety. Through an analysis of a pool fire that occurred in a chemical plant in Colombia, an educational module on fire and explosion safety was developed. The module describes basic concepts related to fire safety such as pool fires, dikes, vapor pressure, and flammability limits, and highlights the differences between prescriptive vs. performance-based design. It also illustrates the use of Physical Modeling Tools (PMTs) as an example of emerging technologies in fire safety.

The module was presented to first-semester students in the Introduction to Chemical Engineering class and advanced students in the Process Engineering class at Facultad de Minas, Universidad Nacional de Colombia Sede Medellín. The impact of the module was evaluated by surveying the students on the perceived importance of the competencies for fire and explosion safety, before and after taking the module, and comparing the results with the order of importance of the competencies as defined

by a group of experts in fire and explosion safety. The module was deemed an effective way to increase the awareness of Chemical Engineering students on fire and explosion safety.

Keywords: fires and explosions safety; pool fire; engineering education.

Resumen

Incidentes como el incendio ocurrido entre el 21 y el 23 de diciembre de 2022 en la instalación de almacenamiento de tanques de combustible en Barranquilla, sirven como recordatorio del riesgo de incendios para las industrias colombianas. Los ingenieros químicos tienen la importante responsabilidad de garantizar diseños y tecnologías que eviten incendios y explosiones. Sin embargo, la seguridad contra estos incidentes no es un tema que se aborde explícitamente en el plan de estudios de Ingeniería Química. Este estudio describe un módulo educativo que fomenta en los estudiantes de pregrado de Ingeniería Química competencias relevantes en seguridad contra incendios. A través de un análisis de un incendio por empozamiento ("Pool Fire") ocurrido en una planta química en Colombia, se desarrolló un módulo educativo sobre seguridad contra incendios y explosiones. El módulo describe conceptos básicos relacionados con la seguridad contra incendios, como incendios por empozamiento, diques, presión de vapor, límites de inflamabilidad y hace hincapié en las diferencias entre el diseño prescriptivo y el basado en el desempeño. También ilustra el uso de herramientas de modelado físico ("Physical Modeling Tools, PMTs") como un ejemplo de tecnologías emergentes en seguridad contra incendios.

El módulo fue presentado a estudiantes de primer semestre en la clase de Introducción a la Ingeniería Química y a estudiantes avanzados en la clase de Ingeniería de Procesos en la Facultad de Minas, Universidad Nacional de Colombia - Sede Medellín. El impacto del módulo se evaluó encuestando a los alumnos sobre la importancia percibida de las competencias para la prevención de incendios y explosiones, antes y después de cursar el módulo, y comparando los resultados con el orden de importancia de las competencias definidas por un grupo de expertos en seguridad contra incendios y explosiones. Los resultados muestran que el módulo fue exitoso con los estudiantes. La aplicación del módulo se consideró una forma efectiva de aumentar la conciencia de los estudiantes de Ingeniería Química sobre la seguridad contra incendios y explosiones.

Palabras clave: seguridad contra incendios y explosiones; incendios por empozamiento; educación en ingeniería.

1. Introduction

Fires and explosions represent a risk for various industries worldwide (Garlock et al., 2012; Jung et al., 2008; Taveau, 2011; Wood, 2021; J. Zhang et al., 2020). The evolution of fire and explosion safety design over the years has been related to the technological advances of each era. Before 1950 and between 1950 and 1990, fire safety designs were carried out empirically and semi-empirically, respectively. It was not until 1990 that PMTs (Physical Modeling Tools) allowed performance-based design (Maluk et al., 2017; Su et al., 2021). Over the past decade, emerging

technologies such as Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), and Big Data (BD), have started to permeate the fire safety community. Some authors (Su et al., 2021; X. Zhang et al., 2021) have even coined the term “smart design” when all these technologies are applied to predicting fire performance in real-time.

Different undergraduate, graduate, and Continuing Professional Development (CPD) programs in fire and explosion safety are offered worldwide (IAFSS, 2023; U.S. Fire Administration, 2023; SFPE, 2023). Commonly, these undergraduate programs focus on encouraging a set of competencies in students, which usually are established by prestigious international entities that accredit the programs, such as the Accreditation Board of Engineering and Technology (ABET) (ABET, 2023), from the United States of America (USA); the Engineering Council (EC) (*Engineering Council*, 2020), from the United Kingdom (UK); and the European Network for Accreditation of Engineering Education (ENAE) (ENAE, 2020), from the European Union (EU). The set of competencies can be divided into hard and soft. Hard competencies refers to abilities to perform a task with a specific knowledge. Soft competencies are related to the attributes or qualities of an individual, but they can be infused by something or someone (Lange et al., 2022).

Colombia does not offer undergraduate programs in the area of fire safety. Most graduate courses related to fires and explosions focus on occupational safety. Only a few CPD courses with the approach of process safety and risk management are offered by universities and industrial organizations (Molina et al., 2022). This study presents an educational module in fire and explosion safety that applies PMTs to foster in students hard and soft engineering competencies that can be used to prevent fires and explosions. The module centers on the investigation of a real fire that took place in Colombia. The use of PMTs in the analysis of the fire exposes students to basic knowledge related to pool fires. The model is then validated and implemented in different student groups and evaluated by surveying students about the importance of engineering competencies for fires and explosions safety.

2. Educational module - Fire in a Tank Storage Facility

The educational module was implemented in two chemical engineering mandatory courses at Universidad Nacional de Colombia - Sede Medellín (UNAL-MED). This approach follows that of (Amaya-Gómez et al., 2019) who considered that the most appropriate learning space for process safety is in mandatory (core) courses. The Fire Dynamic Simulator (FDS) was used to model the fire. FDS uses Computational Fluid Dynamics (CFD) and is designed for fires.

The module includes a theoretical background that describes the physical and chemical phenomena that help to understand the science related to pool fires; the description and possible causes of the incident, and an illustration of the use of FDS in preventing and understanding these fires. A combined specialist/generalist pedagogical approach was implemented in the module (Woodrow et al., 2020).

Students who took the module were divided into two levels; for each group of students, different learning objectives were set, according to the six discrete levels of thinking of Bloom's taxonomy

(M. Woodrow, 2013). The module had two learning objectives: a. to recognize the importance of PMTs and emerging technologies in fire and explosion safety; b. to identify the differences between prescriptive and performance-based design.

Figure 1 presents schematically the general framework of the educational module. Hard competencies were encouraged in the module through the theoretical concepts and the application of FDS to understand fires. Soft competencies were addressed with the description of the consequence of the incident, statistics regarding incidents in Colombia and the world, a description of human safety omissions in the incidents, and class homework.

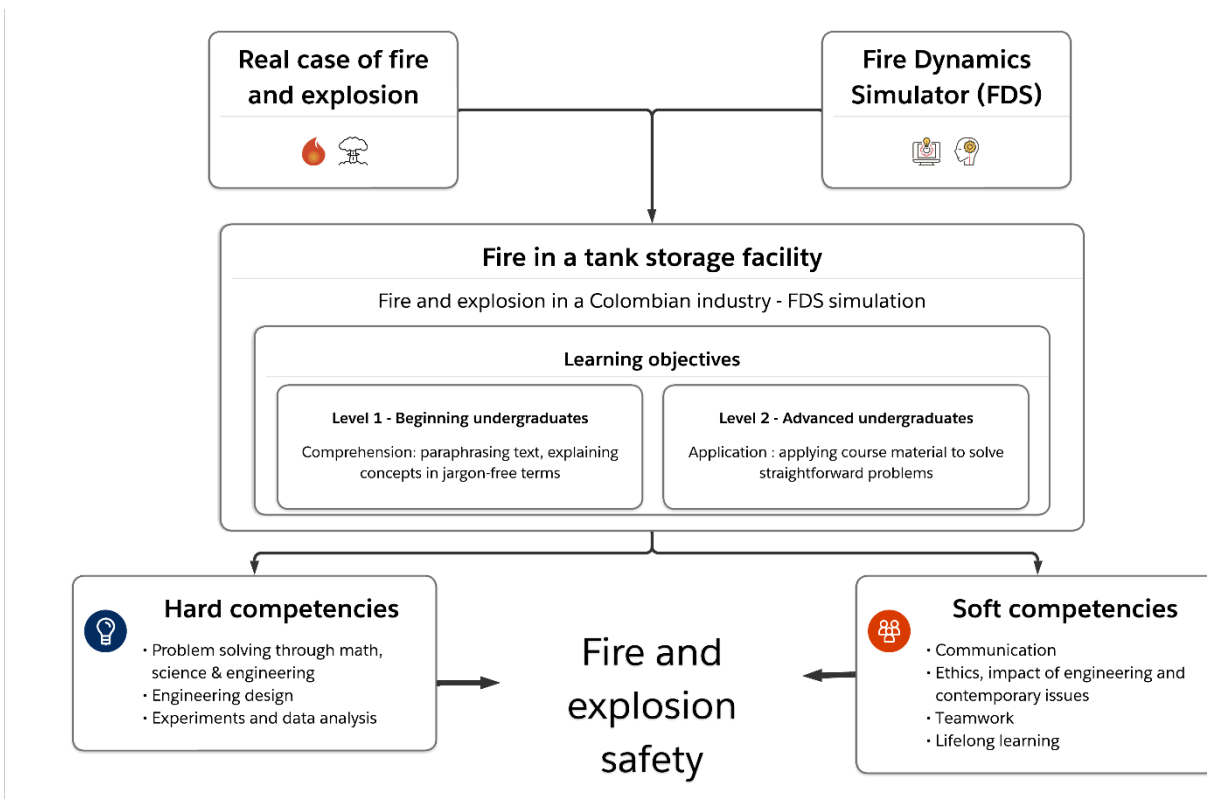


Figure 1. Scheme of the educational module.

2.1 Incident description

An explosion occurred in a xylol storage tank at a chemical company in Colombia. The xylol tank detached from its base and moved like a projectile, leaving a fire trail. Where the tank was anchored, a pool fire ignited on the spilled product. Three people died in this incident.

2.2 Validation and implementation

Before applying the module to the students, a two-step validation was implemented. Firstly, the module was used in CPD courses imparted to workers from the mining industry. Secondly, the

module was used in a two-day course for local engineers. In each step of the validation process, the feedback of students and faculty members was received.

After the validation process, the module was implemented in two mandatory courses of the chemical engineering undergraduate program: Introduction to Chemical Engineering (first semester, 1-h implementation) and Process Engineering (9th semester, 4-h implementation).

The teaching material included: i. support slides to visually present the theoretical concepts, incident descriptions, and simulation results; ii. lecture notes with a description of the module contents and a questionnaire; iii. manuals that illustrated step-by-step instructions to model the fire in FDS. All these materials can be found on the following website <https://github.com/FR-UN/Education.git>.

2.3 Evaluation

To assess the impact of the module on the students, interviews were conducted with different experts on the subject. Similar to the method used by Li et al. (Li et al., 2020), the expert's responses were classified according to their service time, education level, and professional position. The method used to survey the experts was the Analytic Hierarchy Process (AHP).

Regarding students, a survey was carried out in which they were asked about the importance of each student outcome for fire and explosion safety; the questionnaire used a 5-point Likert scale. This survey was done before and after the students took the module, in this way it was possible to compare the students' and experts' results. Importance Performance Analysis (Shyr et al., 2021) was used to compare these results. In [Figure 2](#) the perception of importance of different hard and soft engineering competencies by students (x-axis) was compared to that of experts. A high value of the coefficient of determination R^2 indicates agreement between students' and experts' perceptions.

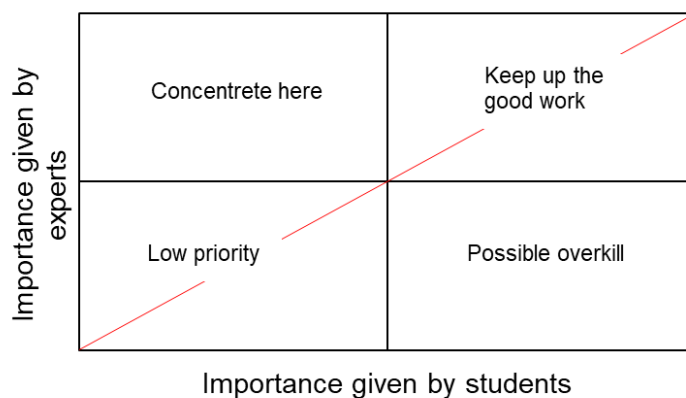


Figure 2. Importance Performance Analysis (IPA) chart used to compare the importance of engineering competencies in fires and explosions education for students and experts (y-axis).

3. Results

Nine experts from the industry, academy, and government were surveyed. Seven experts were from Colombia, one was from the USA, and one was from the UK. The results of the expert survey are shown in Figure 3. The students considered Engineering design and Experiments and data analysis, with 18% each, as the most important competencies in fire and explosion safety; they deemed Teamwork as the least important with 6%. Interestingly, the importance given to hard competencies is of the same order as that of soft competencies.

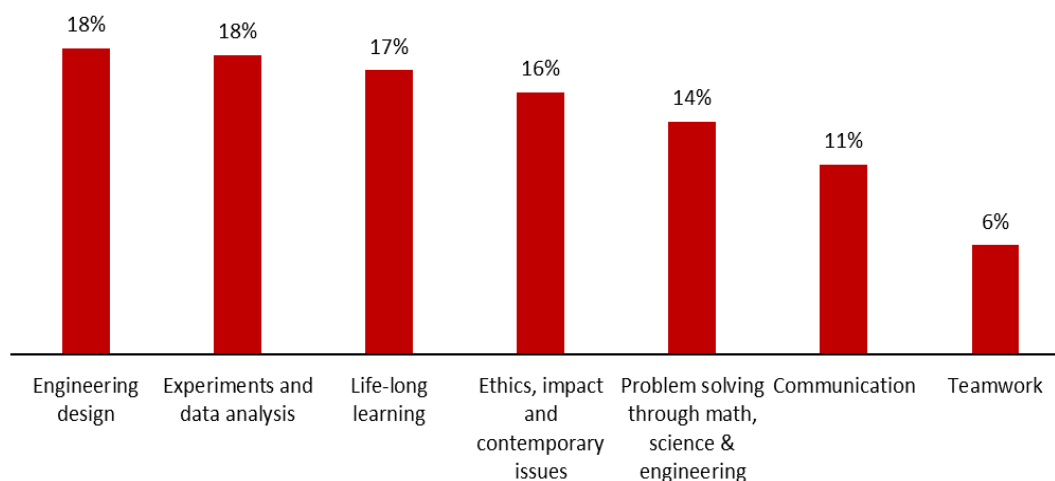


Figure 3. Importance of engineering competencies in fire and explosion safety education according to experts.

Table 1 shows that before taking the module, students of the Introduction to Chemical Engineering course (Level 1) considered that hard and soft competencies were not important in fire and explosion safety as the low value of R^2 (0.04) indicates. However, after taking the module, R^2 for the IPA analysis increased to 0.47. This suggests that the module significantly improved the student's perception of the importance of the competencies required to address fire and explosion safety.

For the more advanced class, Process engineering, R^2 increased from 0.30 to 0.53 after taking the module. While the increase in R^2 was not as evident as that observed for the Level 1 students, the results indicate that the Module raises the student awareness of fires and explosions.

Course	Students level	R^2 Before	R^2 After
Introduction to Chemical Engineering	1	0.04	0.47
Process Engineering	2	0.30	0.53

Table 1. Results of applying the module. A high and low value of the coefficient of determination R^2 represent better and worse results.

4. Conclusions

Chemical engineering students at Facultad de Minas, Universidad Nacional de Colombia-Sede Medellín, at the beginning of their studies, do not relate fire and explosion safety with the engineering competencies that can be acquired during their career. At the end of their studies it could be verified that there is a greater association between engineering competencies and fire and explosion safety; however, this association is lower than that expected, given the responsibility that a chemical engineer has regarding safety.

The application of the educational module, Fire in a Tank Storage Facility, here introduced, significantly increases the awareness of students of the competencies required to address fire and explosion safety. The results suggest that similar modules applied throughout the chemical engineering curriculum can improve the education of fire and explosion safety.

5. Acknowledgments

We dedicate this publication to the memory of the three fatalities of the fire in the tank storage facility that occurred in Colombia.

6. Founding

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