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Viewpoint

Imperative of Integrating Process Safety Education in Chemical Engineering Curricula

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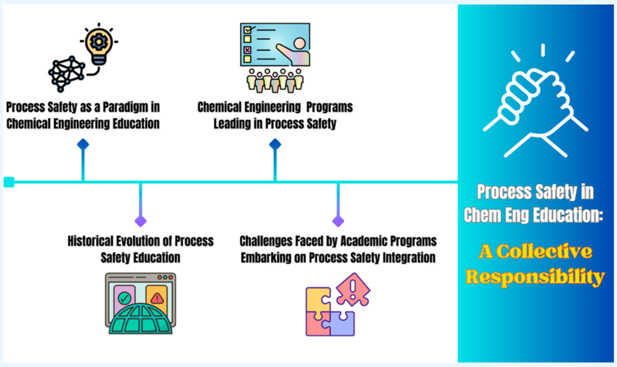
ABSTRACT: The integration of process safety education into chemical engineering programs has become a pressing necessity for chemical engineers worldwide. However, some chemical engineering programs have not yet incorporated process safety into their curricula. The purpose of this Viewpoint is to encourage a discussion on the imperative of mobilizing a global update of chemical engineering education and integrating process safety. This initiative will not only inspire experts in the field to support those seeking this change but also encourage new participants, especially from countries that have not yet embraced this much-needed transformation in chemical engineering education.



■ INTRODUCTION

Any academic program should be understood as an entity that evolves based on the demands of the environment, society, and the productive sector. These needs delineate the educational paradigms within each field, and the curricula of academic programs must adapt accordingly to these paradigms.[1,2] The evolution of chemical engineering programs has been instrumental in advancing human society. Different eras have seen distinct paradigms, reflecting evolving industry and societal needs.[3]

In the late 19th and early 20th centuries, engineers honed Unit Operations, optimizing processes such as distillation and filtration for efficiency. The mid-20th century saw a shift toward Chemical Processing, emphasizing large-scale plant design for chemical, petrochemical, and pharmaceutical production. Later, a holistic approach emerged, considering entire process flows in Process Engineering. Environmental concerns prompted a shift toward Sustainability, prioritizing eco-friendly, efficient processes with minimal waste.[4,5] Bioprocess engineering leveraged biotechnology, while from the late 20th to the 21st century, Process Safety became paramount, emphasizing safe design, operation, and management.[6]

In the 21st century, Data Science and Computational Modeling took precedence, enabling precise process optimization. Interdisciplinary Collaboration and Sustainable Solutions now form the core of addressing global challenges. This shift is accelerated by rapid advancements in Artificial Intelligence, revolutionizing education and equipping the next generation of chemical engineers for an ever-changing world.[7,8]

While process safety has been a pivotal paradigm reshaping chemical engineering education since the late 20th century, the curricular update regarding process safety has not been universally implemented in chemical engineering programs worldwide. This gap has led to a deficiency in the training of new chemical engineers, who have yet to align their programs with this global imperative. The aim of this Viewpoint is to shed light on this situation and issue a clarion call to action for all stakeholders involved in effecting a worldwide curricular update in chemical engineering, centering on process safety. This endeavor will undoubtedly encounter limitations and challenges, but it is essential for ensuring that the next generation of chemical engineers is equipped to meet the evolving demands of the field. But first...

■ BLAST FROM THE PAST: UNEARTHING PROCESS SAFETY EDUCATION

The integration of process safety education into chemical engineering curricula represents a dynamic response to tragic incidents and a commitment to safeguarding lives and the environment. This historical account traces the evolution of process safety education, highlighting key organizations and

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pivotal events, both historical and contemporary, that have propelled this imperative transformation.

The late 20th century bore witness to tragic incidents, such as the Flixborough disaster (1974) and the Bhopal gas tragedy (1984), which laid bare the critical need for process safety education. In the aftermath, the Center for Chemical Process Safety (CCPS) emerged in 1985 as a vanguard organization dedicated to promulgating process safety awareness and education. Subsequent events, including the Piper Alpha platform explosion (1988), underscored the necessity for comprehensive safety education.[9]

The CCPS, an initiative led by the American Institute of Chemical Engineers (AIChE), played a seminal role in shaping process safety education. Guided by CCPS publications like "Guidelines for Process Safety in Batch Reaction Systems", the AIChE became a global advocate for curricular reform. Similarly, the Institution of Chemical Engineers (IChemE) and the European Federation of Chemical Engineering (EFCE) established their own safety-centric initiatives, including IChemE's Safety Centre (2001) and EFCE's Working Party on Loss Prevention.[10,11]

The Deepwater Horizon disaster (2010) served as a poignant reminder of the ever-present need for process safety vigilance. This catastrophic event prompted renewed scrutiny of safety practices and reinforced the importance of robust education in chemical engineering programs.[12,13] More recent incidents, such as the Tianjin explosion (2015) and the Beirut port explosion (2020), further underscored the critical importance of process safety education in an ever-evolving industrial landscape.[14,15]

And the examples keep coming, not limited to these monumental catastrophic events etched in history. Every day, we add events that reaffirm the need to bolster process safety. These are events we cannot classify as "minor" because they, too, have claimed lives, jobs, resources, and consequences for the environment. Leaks, explosions, and fires have made headlines in international news agencies like Reuters and in prominent media outlets such as The New York Times and The Guardian and are recorded in chemical accident databases around the world, including ARIA (France), eMARS (European Commission), ZEMA (Germany), FOD Waso (Belgium), DSB (The Netherlands), and CSB (United States), among many others.[16−18]

As a result, the profound impact of these events and the dedicated efforts of the aforementioned organizations have led to a robust integration of process safety education into the curricula of chemical engineering programs. Universities in close proximity to these seminal occurrences, particularly in countries such as the United States and the United Kingdom, have emerged as leaders in championing this crucial aspect of engineering education. So, which programs are pioneers in this integration?

PIONEERING PROGRAMS: LEADING THE WAY IN INTEGRATING PROCESS SAFETY EDUCATION

Numerous prestigious universities worldwide have adopted a pioneering approach, facilitated by organizations like CCPS and AIChE, to seamlessly integrate process safety education into their chemical engineering curricula. In the United States, institutions such as Texas A&M University, Georgia Tech, and the University of Michigan, among others, have made significant strides in this endeavor. These universities offer specialized courses, ensuring that graduates acquire a robust foundation in managing hazards associated with chemical processes.[19,20]

Across Europe, there has been a concerted effort to foster a safety culture in higher education. EFCE has championed the inclusion of process safety in both bachelor's and master's degree programs.[21] Institutions in countries such as the United Kingdom, Belgium, The Netherlands, and Italy have enthusiastically responded to this call. For example, the University of Oxford, Imperial College London, and the University of Manchester in the UK have incorporated process safety courses into their curricula, aligning with the recommendations of IChemE, which ensures that process safety courses in the UK adhere to high-quality standards.[22]

Beyond these leading nations, other regions have also recognized the paramount importance of process safety education. In China, the rapid expansion of the chemical industry has compelled the government to prioritize safety and environmental considerations. Chinese universities have been proactive in integrating process safety courses to ensure that their graduates are well-prepared to navigate the intricacies of modern chemical processes securely.[23]

Whether attributed to their longstanding leadership in this subject matter or their strategies inspiring those embarking on this journey, the pioneering institutions have paved the way for comprehensive integration. The methods employed by chemical engineering programs worldwide are diverse and compelling. Many adhere to the conventional approach of incorporating specific process safety courses into the curriculum, with some offering well-documented experiences, as evidenced by institutions like Imperial College,[24] Michigan University,[19] Dalhousie University,[6] and Otto von Guericke University,[25] among numerous others. However, alternative models have also emerged, showcasing the creativity and adaptability of the committed institutions in addressing this crucial topic.

Some programs have directly linked process safety to laboratories and experimental work within research environments, such as Northeastern University[26] and Texas A&M University.[27] Others have embraced the combined efforts of academia and industry as a means to achieve their goals in process safety education. This approach has been undertaken from various perspectives: certain programs have incorporated industrial protocols into process safety courses, as observed at Dalhousie University,[28] while others have fostered collaboration between university professors and industry experts, as demonstrated in the documented cases at South Dakota School of Mines and Technology[29] and Georgia Tech.[30] The latter's successful initiative, PALS, in partnership with ExxonMobil, serves as a testament to the fruitful collaboration between academia and industry, setting a standard for others to follow.

However, even in regions where the efforts of organizations and academia have joined forces to enhance process safety in chemical engineering programs, there are cases where the integration of process safety hardly ensures the development of solid competence in students. At times, it is addressed as a standalone course or even as an elective, without receiving the same emphasis as other aspects of chemical engineering.[20] If these differences are still noticeable in pioneering countries, what can be said for countries that began addressing this only much later, long after the catastrophic events of the late 20th century? What are the challenges and limitations that

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universities face in integrating process safety into their chemical engineering curricula?

■ OVERCOMING HURDLES: INTEGRATING PROCESS SAFETY INTO CHEMICAL ENGINEERING PROGRAMS

If we are going to discuss the challenges of integrating process safety into a Chemical Engineering curriculum, allow me to do so from a first-person perspective, drawing on my personal experience as the Coordinator of the curriculum update for the Chemical Engineering program at the Universidad del Valle—Colombia. From this standpoint, I can affirm that the hurdles faced by universities in this integration can be quite diverse. Those who have navigated curriculum updates in this domain will likely recognize parallels to some of these key points.

First, there may be institutional resistance or a lack of dedicated resources to develop and implement specialized courses in process safety. Many of our institutions grapple with curriculum updates without a specific allocation of resources, both human and material. Highlighting this point in the current discussion aims to shed light on the necessity of institutional commitment, which stems from a clear origin: WILLINGNESS. While resources may not be abundant, a curriculum change requires a genuine desire to make it happen, even if the initial steps toward that goal are small—every effort counts!

Moreover, maintaining up-to-date process safety content to align with the latest industrial practices and regulations presents a significant challenge, particularly in light of resource limitations. Equally crucial are the proper training and continuous education of professors in this field to deliver effective process safety instruction. It requires actively involving a significant portion of the faculty in the discipline. In addition to having knowledgeable professors, it is imperative to provide opportunities for other faculty members to update and enhance their skills, where institutional willingness plays a crucial role. This proactive approach ensures that a broader spectrum of faculty members can contribute effectively to curriculum updates.

And why does it involve the entire faculty (or at least a significant portion)? Because the most effective way to integrate process safety is by making it a pervasive thread throughout the curriculum, it becomes a cross-cutting axis. This means addressing safety not only in specialized courses but also in foundational courses of chemical engineering. It involves classroom activities and experiential learning in laboratories and culminates in final capstone projects.[31] This undoubtedly engages many faculty members who may not have been previously involved in this paradigm.

This leads us to overcome another challenge—the balance between process safety and the content of other fundamental aspects of chemical engineering. However, it is essential to understand that process safety does not replace foundational knowledge; it is integrated into the core of the discipline, providing a comprehensive safety perspective. Yet, this endeavor aspires to an even greater goal: to instill in the student a culture of safety, such that they advocate for it in every aspect of their role as a chemical engineer.

Here, it is important to recognize that this overarching goal is perhaps the most intensive in terms of resources and commitment. It entails not only the seamless integration of knowledge across the curriculum, delivered by professors who embrace and deeply understand this paradigm, but also the incorporation of tools (such as specialized software) and, more importantly, hands-on experiences that enable students to engage with process safety in real-world scenarios. At this stage, a new factor comes into play: the external support. Industry, related organizations, and institutions that have advanced along this path are instrumental. Their participation is indispensable in ensuring the ongoing relevance and applicability of this integration for universities that are just embarking on this journey. So, here is the call to action.

■ RALLYING OUR PROCESS SAFETY LEADERS: A CALL TO ACTION

Undoubtedly, the pioneering institutions in process safety in chemical engineering have served as inspiring examples. Many of us, in the process of curriculum updates to integrate process safety into our academic programs, refer to the information provided by universities and organizations. This allows us to construct an integration tailored to our resources and personnel capabilities, overcoming the challenges of the process with the mentioned key weapon, willingness. However, in retrospect, those institutions with experience can play a more proactive role and be more than just a source of inspiration. They can become agents of change in favor of a global safety culture, bridging the educational gaps for chemical engineers worldwide.

The journey of universities toward integrating process safety should not be a solitary path. What if we support each other along the way? One crucial avenue is knowledge sharing and collaboration. Establishing partnerships between universities with established process safety programs and those in the early stages of the process allows for dynamic exchanges of ideas and experiences. Workshops, seminars, and sessions can facilitate interactions between faculty members and experts, enriching their understanding of process safety principles.

Furthermore, process safety leaders can provide invaluable support through faculty training. Comprehensive programs covering methodologies, best practices, and safety-related tools empower faculty members in universities in which process safety integration is needed. Additionally, leaders can extend their support to curriculum development by offering guidance, sharing resources, and leveraging successful approaches from existing programs. This collaborative effort empowers institutions to build a curriculum that aligns with international standards and meets the unique needs of their students.

In conclusion, as a community of chemical engineering education, we have a critical call to action: to ensure a global update of chemical engineering curricula by seamlessly integrating process safety. This means not only making it a reality within our own universities but also advocating for its implementation in others. It will not be sufficient for our institution to have a well-established and renowned process safety program. Our collective effort must persist until every institution ensures the development of professionals with a safety-oriented ethos, preventing the recurrence of incidents that once underscored this pressing need.

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