How have chemical and industrial accidents shaped the evolution of safety education in chemical engineering programs?

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

In 2008, a graduate student, Sheri Sangi, tragically passed away while conducting research in her academic laboratory at UCLA. She was handling tert-butyllithium which ignites spontaneously when in contact with air without wearing proper lab safety gear. UCLA was fined $31,875 for workplace safety violations after her death. They were also charged with felony violations of California labor laws. Her death is seen as a catalyst for pushing other academic labs to improve their safety culture (Kemsley, 2018).

As a chemical engineer, there are dangers associated with any field I choose to pursue. Chemicals can be toxic, hazardous, or explosive. A chemical accident could have major consequences so it is important for a chemical engineer to be educated in process safety to prevent them from occurring. As expensive or time consuming people think safety education is, they should try seeing how expensive an accident is.

In 2010, an explosion in the Deepwater Horizon oil rig led to the deaths of 11 workers as well as 134 million gallons of oil spilled into the Gulf of Mexico. The environmental and economic impacts of this disaster are still felt today. BP was found responsible for this spill and is responsible for paying over $20 billion dollars in fines and repairment costs (Monnier, 2021). Even with the repair efforts, the Gulf of Mexico faces long term damages to the marine life in it. The time spent cleaning up this mess and dealing with the emotional consequences outweighs the time it could have taken to learn and implant safety measures into BP that could have prevented this accident from occurring.

Both of those above accidents show just how important safety education is for chemical engineers. One small safety violation could lead to deadly consequences in this field filled with hazardous chemicals. These types of process safety accidents over time have impacted industry practices as well as the education programs required for chemical engineers.

I will examine how these industrial accidents have shaped chemical engineering safety education by analyzing changes in industry regulations and curriculum. I will be analyzing major disasters and seeing what consequences they had on both industry and academics. Throughout history, major industrial accidents have been a driving force for changes in safety education, as safety education is reactive rather than proactive and still has gaps that can be identified.

Lit Review

A process safety disaster in an industry or academic setting is a driving force for changes behind safety procedures. It is not just specific to the chemical engineering discipline. Anytime a disaster has happened it causes people to search for the cause to look for ways to prevent it. For example, in the medical field, every time a patient dies the cause of death is analyzed. If the cause of death is found to be the fault of the doctor, the doctor’s mistake is then looked into (Deis et al., 2008). The hospital will then look into the future to figure out ways to make sure that doctor’s mistake is never repeated. Another example of this pattern is in the aviation industry. If a plane crashes due to a pilot's human error, flight schools will alter curriculum to make sure that pilot's error is not repeated by another person. All incidents show that safety education is reactive to accidents instead of proactive as it only becomes a priority to alter after a tragedy has shown its flaws.

Chemical Engineering has also followed a pattern of reactive safety education with major accidents leading to the most amount of change. The biggest chemical industrial accident was the Bhopal incident where a storage tank containing toxic methyl isocyanate leaked and released the gas. The total death count is unknown, but the commonly accepted number is 2000 people. Tens of thousands of people were severely injured and a lot of them passed away before their time due to their exposure in the following months and years (Duhon, 2014). This disaster was a catalyst that led to an increase of government involvement in safety education as well as the creation of the Center for Chemical Process Safety (CCPS) (Willey et al., 2005).

While chemical engineering safety education has evolved, there is research showing that it is still not consistent across all university programs (Dee et al., 2015). Most universities, including UVA, only have safety education isolated into one course instead of being integrated into all the different courses students take. Other engineering disciplines, such as nuclear, have safety education embedded into every course they take so they are continuously thinking about the safety concerns where chemical engineers see it as an isolated topic. Organizations such as AICHE have tried to make safety education for chemical engineers consistent and more hands-on (AICHE, 2025). However, with no standardized formula for safety education within all accredited chemical engineering universities, there is no way to know if all chemical engineers are entering industry with proper process safety knowledge.

While analyzing how chemical engineering safety education has evolved I will be using the framework as seen in Frazier's "A Hierarchical factor analysis of a safety culture survey." Using this framework will let me split safety culture into measurable factors which show how structured a safety culture is. The four components of safety education used in this paper are management commitment, personal responsibility for safety, peer support, and safety management systems (Frazier, 2012). This study focuses on industry safety practices, but for the purpose of my research I will be applying it to academics. Management commitment is the factor that discusses how a strong leadership team that prioritizes safety promotes a better safety culture in the organization. Universities need professors and administrators to really care about safety to ensure their safety education is properly implemented. Personal responsibility is making sure that the employees take accountability for their actions that contribute to the overall safety of the team. Peer support discusses how members of the team support each other when being safe while also not being afraid to speak up when they see a team member practicing unsafe behaviors. Lastly, safety management systems are the structured safety measures in place such as emergency response plans and hazard analysis methods. Applying this framework will allow me to see how effective safety education is and see if it has successfully adapted after the industrial accidents.

Methods

For this research I will be analyzing case studies of industrial accidents, and their effects on the education system. The case studies will come from a variety of sources that account for what occurred and what was the root cause of the accident. I will use academic research journals to figure out the effects of the accidents and the impacts on curriculum. Also to find the effects, I will be looking through regulatory agencies such as ABET and OSHA to determine they implemented major standards and changes to university programs. My framework comes from an old thesis of a graduate student at Appalachian State University because his research was also studying safety education.

Analysis

Over time, major process safety accidents in industry have been a driving factor for shaping safety education in chemical engineering curriculum. An accident occurs in industry which then shows a gap in the system that needs to be addressed so an accident like that does not occur again. As mentioned earlier, the Bhopal disaster in 1984 was one of the deadliest accidents in chemical engineering history. The causes of the disaster were analyzed immediately and found to be lack of worker training and poor hazard management plans which shows how important a safety management system is to a company. After the Bhopal disaster, the United States along with AICHE created the Center for Chemical Process Safety (CCPS) (Willey et al., 2005). The Bhopal disaster was also the reason the Process Safety Management standard was set in the US (OSHA, 1992). However, those are changes in safety practices in industry. Changes in process safety education came later. In 1992, after the CCPS had been operating for a bit, they then expanded their mission to create the Safety in Chemical Engineering Education (SaChE) (Forest, 2018). The goal of this mission was to provide content for professors to easily be able to incorporate into their already existing curriculum for students. This was the first time that it was suggested by an organization that process safety education should be part of the curriculum taught to undergraduate students.

Another major disaster that had a direct impact on safety education changes was the Texas City Refinery explosion in 2005. A hydrocarbon isomerisation unit was restarted after being down for maintenance. The level indicator alarm was broken so the tank was overflowing causing flammable vapors to vent to the atmosphere which ignited causing the explosion (Gurung et al., 2020). After investigation it was found that BP had a lack of a management committee for safety so no one was solely responsible for addressing the warnings of unsafe conditions. This incident created an emphasis on case studies in process safety education. After this incident, when students learned process safety they analyzed real consequences about not taking safety seriously instead of just memorizing safety practices (Kletz & Amyotte, 2019).

Another case study already mentioned, the death of graduate student, Sheri Sangji, at UCLA also had impacts on the safety education system at Universities. Her death showed safety failures within university research labs as it was due to a lack of proper protective equipment. It was due to lack of safety management and peer support overseeing the rules making sure they were enforced. Her death led to immediate changes as mandatory lab safety training programs became implemented at many universities (Gordon, 2011). It also led to faculty putting a stronger emphasis on safety regulations in their labs and classrooms. However, many universities still treat safety education as a requirement rather than an integral part of education which causes students to not understand its importance.

All three of these case studies show how incidents have a direct impact on chemical engineering curriculum being changed. While some impacts are faster than others, they all had an impact on the programs. They also all showed how the gaps identified during the incident were addressed by programs to show on the earlier point that safety education is reactive to incidents. Some may argue that technology is a driving force for changes in safety education rather than accidents. This would be because as technology evolves, it is easier to create better systems and alarms for safety features. For example, as automation systems could be used to detect when a valve is faulty or a tank is overflowing now where back when the Bhopal disaster occurred, the systems were not as automated. However, while technological advancements do influence a lot of curriculum updates, they lack the urgency that accidents create. Accidents create a better need to change curriculum because they showcase real fatal consequences of human errors due to lack of education. The fast changes to education and industry standards after all three of those case studies show just important accidents are creating change rather than technological advancements.

While accidents are a driving force for safety education, it is still not uniform across all universities. Each university has a different approach to safety education so a lot of graduates going into industry are not adequately prepared for the challenges. There are organizations such as ABET and the CCPS that recommend education programs, but they have not created a universal standard for implementations. There are some universities that integrate safety education into their curriculum, such as requiring students to conduct hazard analysis and risk assessment throughout their studies. However other schools just treat it as an add on to their laboratory classes (Hill, 2016). In 2024, a study revealed that 27% of students at various universities reported they did not receive safety training before entering a lab. This same study then asked about if students wore proper protective equipment in the lab, and only 57% of students reported they wear safety goggles in the lab (Sonewane et al., 2022). The students reported they felt pressure from their peers to remove the safety goggles as they felt resented for taking safety procedures seriously. While schools are required to teach safety now to students, they are not closely monitored to ensure that students are prepared to handle safety in industry.

A common weakness of most safety programs in universities is the lack of hands-on training. Students learn about the concepts, but if they do not do hands-on training it will be hard for them to apply what they have learned (Hill, 2016). Simulations and industry collaborations are proven methods for safety training, but they are not utilized by institutions (Elendu et al., 2024). Some universities do incorporate process safety labs into their curriculum where students are able to practice emergency response and incident investigation. However other schools rely on power points to portray the information.

One of the measures to determine how effective a safety program really is to understand how the students feel after going through it. Students enrolled in US universities have said they feel underprepared when it comes to safety education (Sofri et al., 2022). While students are being taught safety education, they are not learning how to implement it. Universities need to collaborate with industry to address the skills that students should be prepared for after they graduate. Safety education has improved due to major accidents, but there are still gaps that should be found before another accident occurs.

As mentioned earlier, industrial disasters have a lot of impact on the way industry reacts to safety. As schools want to train their students for industry, when companies make changes to safety programs, the universities then also make changes. In 2014, DuPont in La Porte, Texas, leaked methyl mercaptan resulting in the deaths of four workers. A vent was blocked so when attempting to clear the blockage, workers opened a valve which released the toxic gas into the building (EPA, 2023). After investigating, it was discovered that DuPont had a history of safety violations, which included failure to properly give their employees safety training upon arrival. This reinforces the principle that management commitment is important because if the employees are not informed about the importance of safety when they arrive they won't take it seriously. In response to this incident, DuPont along with other companies, added improved ventilation and detection systems into their plants. It also had some universities begin analyzing human error when discussing safety education.

Another disaster that had direct impacts on industry safety standards was the West Fertilizer Plant explosion in Texas in 2013. Ammonium nitrate was not stored properly, so when a fire broke out due to faulty electrical wiring with no sprinkler system, it caused the ammonium nitrate to detonate and explode (Allen & Gimbel, 2023). Ammonium nitrate was stored in a wooden building which increased the fire risks. The explosion killed 15 people and damaged hundreds of homes. This disaster led to changes in chemical storage standards as that was a big factor in this disaster occurring. The Chemical Safety Board created stricter safety requirements for chemical storage (CSB, 2023). As another result, universities also started to teach storage materials in their safety courses as universities get their inspirations from companies' teachings and accidents.

Conclusion

After finding the causes of industrial accidents, it shows how reactive safety education for chemical engineers is. From the UCLA laboratory death to the Bhopal incident, all of these case studies show that not having proper safety education has had tragic consequences throughout history. The majority of safety accidents have been found to have root causes that could have been prevented if proper safety had been in place. Hopefully in the future, safety education will be proactive so gaps can be filled before they are identified by another tragic accident. At the moment at UVA, process safety is a one credit course required for chemical engineers, but if more accidents occur it could turn into a three credit course or a series of courses or even a minor. I learned a lot this year in my safety course, and I am applying the theory that I learned last semester in my technical capstone project. However, I am not positive I have enough safety training to be able to approach safety in industry when the consequences could be fatal. Future research on this topic would be a comparative study to compare how different universities and companies teach safety. I would like to do a deeper search into how other universities teach safety, and if it is embedded or if it is a stand alone class. I believe if it was embedded into all of my other classes I would have a better understanding, as I would be practicing safety techniques along with doing my work because that would mirror how safety is done in industry.

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