Industrial-Academic Collaboration to Teach Chemical Process Safety

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Introduction

Designing and operating chemical processes in a safe manner is a key job requirement for practicing chemical engineers. Chemical engineers working in industry spend extensive amounts of time reviewing the safety of the facilities in which they work, and are frequently asked to review the potential hazards of processes or changes in the operation of those processes. For this reason, employers of chemical engineers expect chemical engineering students to acquire a strong background in chemical process safety during their undergraduate studies.

Safety education in general and within chemical engineering specifically is an essential but a historically overlooked topic within chemical engineering education. Initiatives have been implemented within the chemical engineering community to enhance education on chemical process safety. The Safety and Chemical Engineering Education (SAChE) program was initiated in 1992 to provide teaching materials and programs to enhance the teaching of process safety at the undergraduate and graduate levels (Anonymous, 2018). This program is a cooperative effort between the Center for Chemical Process Safety (CCPS) and universities. Initiatives started by SACHE include an on-line certificate that students can earn by completing several modules on safety and the SAChE Student Design Competition for Safety in Design that recognizes students who do an outstanding job considering process safety in their submission to the American Institute of Chemical Engineers (AIChE) student design competition.

However in 2007, a reactive chemical explosion at T2 Laboratories killed four employees and injured 13 more people, including multiple civilians. Within their final report, the Chemical Safety Board emphasized the critical need to improve chemical process safety and hazard recognition education within undergraduate chemical engineering programs. The final CSB report recommended that the Accrediation Board for Engineering and Technology (ABET) and the American Institute of Chemical Engineers (AIChE) ensure reactive hazard awareness is included within ChE curriculum (U.S. Chemical Safety and Hazard Investigation Board, 2009). In response, many programs, ours included, have also added a safety class to the curriculum and industry has begun offering process safety workshops for faculty.

The above initiatives have undoubtedly improved student understanding of process safety, but they fail to directly engage industry process safety experts in educating students. Industry engagement has been found to be an effective tool for and training students in relevant professional skills. Given the importance of process safety in the daily job of practicing chemical engineers, engaging practicing chemical engineers in educating the next generation of chemical engineers has significant potential.

A partnership between the chemical engineering department at Kansas State University and Cargill has been established over the past two years to enhance process safety education in a capstone design course. In this partnership, each student design team was assigned a safety coach from Cargill. This safety coach provided input on how the teams should modify their designs to enhance process safety, and provided guided practice on using an established industrial tool (Hazards and Operability (HAZOP) analysis) to analyze safety of a new design. This paper reports on the impact of this collaboration by analyzing student survey data before and after the semester and student performance data on the safety component of their design reports. It is shown that the industrial-academic collaboration positively impacts students, most significantly by enhancing their ability to apply HAZOP analysis to their design.

Implementation of Industrial- Academic Collaboration

The industrial-academic collaboration was first implemented in spring, 2017 in ChE 571 Chemical Engineering Systems Design II. This course is the capstone design course in the chemical engineering program. The collaboration was continued in spring, 2018 in virtually the same form as in 2017.

Cargill safety coaches were incorporated in the ChE 571 by helping student design teams evaluate process safety in their assigned design projects. The collaboration was begun in each semester by a kick-off meeting at which a Cargill representative described Cargill's perspective on process safety. The design teams then met with the Cargill safety coach via a conference call twice during the semester. In the first meeting held early in the design process, the different process design options were presented to the coach and the chemicals being used.. The safety coach provide a perspective on the different options and choices the design team could make that would impact the inherent safety of the process. The coach also provided the team with a few codes, standards or Recognized and Generally Accept Good Engineering Practices (RAGAGEP) that may be applicable to their process (i.e. NFPA). Lastly, the coach provided the team with tools that could be used to understand potential problems associated with chemical interactions in their process, including the chemical reactivity worksheet (Center for Chemical Process Safety, 2018).

The next meeting was held towards the end of the design, when the design team had finalized its design. The focus of this meeting was to conduct process hazards analysis on one unit within the design. The unit being analyzed was selected by the academic instructors in consultation with the Cargill safety coach. This second meeting consisted of a three-hour conference call where the design team conducts a process hazards analysis using the hazards analysis and operability (HAZOP) approach. This is a common methodology used in the industry to identify the risks associated with the process and evaluate if they are mitigated appropriately.

Evaluation of Impact of Industrial-Academic Collaboration

Two measures were collected to evaluate the impact of the use of Cargill safety courses in ChE 571. The first was a survey of students that had them reflect on their motivation, anxiety, and ability to complete various tasks related to process design and process safety. The survey also asked for their opinion on the importance of safety at the industrial level. The second assessment method was to compare student scores on their design reports. Students complete three different design reports in their senior: a team report based on their design project in ChE 570 Chemical Engineering Systems Design I, a team report associated with the AICHE design competition, and a team report for a design project on the "local" design project (projects selected by the course instructors). The Cargill safety coaches assist the students only on the last design project. This allows a comparison of students' ability to perform process hazards analysis with and without receiving input from industrial practitioners.

Results and Discussion

Survey results are shown in Table 1. In 2017, 38 students took the pre-semester survey and 10 took the post-semester survey, while in 2018 39 students took the pre-semester survey and 31 took the post-semester survey.

Table 1. Survey results from 2017 and 2018. Numbers are shown are averages, while the standard deviation is shown in parentheses.

	2017 Pre	2017 Post	2018 Pre	2018 Post
Motivated to – Conduct Engineering Design	64.2 (19.6)	75.6 (19.1)	76.3 (16.9)	65.1 (23.0)
Motivated to – Identify a design need	69.8 (15.7)	77.3 (15.1)	80.7 (14.7)	75.1 (22.4)
Motivated to – Construct, evaluate, and test a design	70.5 (19.3)	78.1 (16.4)	81.5 (16.6)	74.6 (22.2)
Motivated to – Select the best possible design	73.7 (17.9)	72.7 (21.1)	84.6 (15.30	75.6 (17.4)
Motivated to – Construct a prototype by using a process simulator	63.7 (22.5)	72.1 (20.0)	76.4 (20.2)	69.4 (23.9)
Motivated to – Communicate a design	68.7 (20.8)	72.5 (17.2)	81.2 (12.5)	70.7 (22.6)
Motivated to- Conduct a process hazards analysis (PHA)	58.5 (26.5)	59.9 (26.3)	71.5 (21.1)	66.6 (22.9)
Motivated to – Use the HAZOP approach to consider safety hazards for a unit operation	56.0 (24.0)	60.4 (26.0)	72.8 (23.9)	71.3 (22.1)
Motivated – Identify safety risks in a process design	64.3 (24.6)	68.4 (20.7)	79.3 (21.9)	74.3 (21.9)
Motivated to – Implement the principles of inherently safer design	69.1 (21.4)	62.5 (22.4)	82.1 (20.8)	77.3 (22.1)
Motivated to – Access resources related to process safety	65.2 (25.5)	63.2 (26.7)	75.5 (23.0)	72.4 (22.9)
Anxiety to – Conduct Engineering Design	38.9 (28.2)	33.7 (20.5)	50.3 (26.5)	42.9 (23.1)
Anxiety to – Identify a design need	31.7 (23.7)	29.8 (20.8)	38.9 (26.5)	31.1 (21.1)
Anxiety to- Construct, evaluate, and test a design	36.9 (22.9)	26.2 (18.3)	49.5 (26.8)	36.6 (22.2)

Anxiety to – Select the best possible design	35.2 (23.4)	34.7 (19.7)	51.3 (29.2)	38.3 (23.8)
Anxiety to – Construct a prototype by using a process simulator	40.8 (22.0)	29.0 (18.7)	46.3 (24.4)	35.8 (23.8)
Anxiety to – Communicate a design	30.2 (23.7)	38.3 (16.0)	36.1 (26.5)	36.6 (22.2)
Anxiety to- Conduct a process hazards analysis (PHA)	43.9 (25.1)	37.2 (18.1)	47.9 (25.3)	37.4 (24.0)
Anxiety to – Use the HAZOP approach to consider safety hazards for a unit operation	43.7 (27.3)	37.4 (18.0)	49.1 (26.6)	35.7 (24.7)
Anxiety – Identify safety risks in a process design	33.6 (22.4)	33.4 (18.6)	42.7 (31.1)	31.7 (25.9)
Anxiety to – Implement the principles of inherently safer design	29.4 (24.0)	27.1 (17.1)	40.2 (24.1)	28.0 (24.1)
Anxiety to – Access resources related to process safety	24.4 (24.0)	25.4 (14.3)	20.0 (16.2)	25.5 (24.8)
Success in – Conduct Engineering Design	58.4 (24.2)	84.1 (11.6)	68.4 (18.8)	71.9 (20.6)
Success in – Identify a design need	64.7 (19.9)	79.0 (17.4)	72.9 (16.9)	77.1 (16.6)
Success in- Construct, evaluate, and test a design	63.8 (19.8)	80.5 (17.0)	67.0 (22.2)	71.8 (21.5)
Success In – Select the best possible design	66.2 (21.6)	80.5 (13.4)	72.1 (18.5)	73.3 (19.9)
Success in – Construct a prototype by using a process simulator	63.2 (23.0)	81.8 (12.6)	71.6 (22.5)	71.7 (22.3)
Success in – Communicate a design	68.5 (22.4)	81.4 (11.6)	79.4 (19.5)	77.6 (19.2)
Success in- Conduct a process hazards analysis (PHA)	55.7 (27.9)	75.1 (7.3)	60.7 (25.6)	75.0 (17.9)
Success in – Use the HAZOP approach to consider safety hazards for a unit operation	52.0 (28.6)	72.5 (9.5)	57.9 (28.5)	76.1 (18.8)
Success In – Identify safety risks in a process design	61.6 (23.5)	77.6 (10.2)	67.1 (24.3)	78.8 (18.9)
Success In – Implement the principles of inherently safer design	58.9 (25.0)	74.8 (10.2)	72.5 (22.2)	79.5 (17.7)
Success In- Access resources related to process safety	67.5 (28.8)	79.6 (16.5))	81.4 (20.3)	84.0 (12.8)
What percentage of a practicing engineer's time do you think is spent considering process safety? - % of time spent considering process safety	57.4 (19.7)	63.2 (13.8)	56.8 (24.4)	63.1 (22.6)
How early in process design (as a percentage towards completion) do you think that process safety should be considered? – How early in design as a % towards completion is safety	22.2 (28.4)	13.9 (21.1)	16.3 (26.8)	22.3 (30.5)
What is the relative importance of process safety versus process economics? Answer on a scale from 0 to 100 (0 = process safety is not important as compared to process economics; 50 = process safety and process economics are equally important; 100 =	74.5 (21.4)	73.3 (18.9)	75.4 (20.8)	65.2 (15.9)

process economics is not important as compared to process safety). – Relative importance of process safety to process economics				
How important do you think process safety is to chemical companies relative to other metrics (profitability, shareholder value, corporate image, etc.)? Answer on a scale from 0 to 100 (0 = not at all important relative to other metrics; 50 = moderately important; 100 = more important than all other metrics). – Relative importance of safety to companies	75.1 (16.7)	83.1 (19.5)	73.1 (22.7)	68.6 (14.2)

Survey results showed little difference in student motivation for various process design tasks. Nearly all measures of student anxiety about process design and process safety tasks decreased from the pre-semester to the post-semester survey. The results also showed almost uniform improvement in student estimates of their success at completing tasks related to process design and process safety. Statistical analysis was conducted to determine whether the noted changes in student anxiety and student confidence of success were statistically significant. For this analysis, a t-test for two independent samples was conducted. Table 2 shows the results of the statistical analysis.

Table 2. Survey questions that were found to give a statistically significant change from the pre-semester to the post-semester surveys

Statistically significant change between pre- and post-semester survey results	2017	2018
90% significant level	Success in - Identifying a design need	
	Success in – Selectin the best possible design	
	Success in – Conduct a process hazards analysis (PHA)	
	Success in – Identify safety risks in a process desisn	
	Success in – Implement the principles of inherently safer design	
95% significance level	Success in - Conduct engineering design	Success in - Use the HAZOP approach to consider safety hazards for a unit operation
	Success in - Construct, evaluate and test a design	

	Success in - Construct a prototype by using a process simulator	
	Success in - Use the HAZOP approach to consider safety hazards for a unit operation	

Notably, the students response on the success at conducting a process hazards analysis and implementing the principles of inherently safer design was statistically higher at the end for the semester at the 90% significance level in 2017, while in both 2017 and 2018 the student ability to successfully use the HAZOP approach to consider safety hazards for a unit operation was statistically higher after the semester had ended. Since the key component of the Cargill mentoring program was the phone conference where the Cargill coaches guided the students through a HAZOP analysis, it is not surprising that the students felt more confident in their ability to conduct a HAZOP analysis.

Results of the comparison of student design reports is shown in Figure 1.

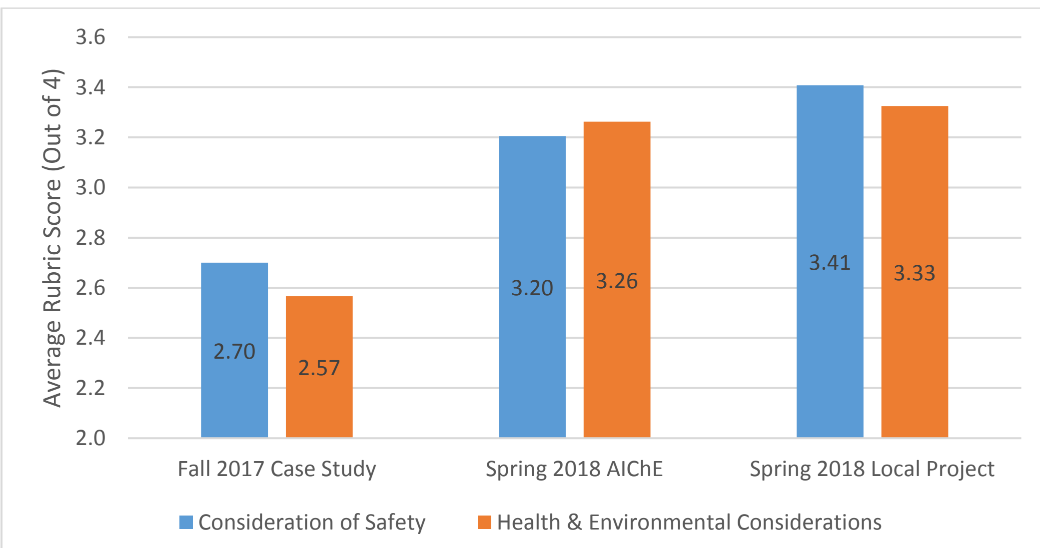

Figure 1. Student performance on design reports on "Consideration of Safety" and "Health and Environmental Considerations", as judged by instructor scoring on a four-point rubric

As seen in Figure 1, student scores markedly improved from the fall, 2017 project to the design reports in the spring for both "Consideration of Safety" and "Health and Environmental Considerations". A further, smaller increase in both areas is noted from the AICHE design report (turned in on March 16th, 2018) and the local design project (turned in on May 4th, 2018).

There can be a number of explanations for the increases in student performance relative to plant and environmental safety. Students received faculty feedback on each design report that could be used to improve performance on the next report. Students took a one credit-hour course (ChE

565 Healthy and Safety in ChE) related to process safety in the spring semester that should have improved their understanding of process safety. Finally, interaction with the Cargill safety coach may have improved student performance. It is difficult to separate out these effects when comparing fall, 2017 data with the spring 2018 AICHE project data, since all three could have been important. Comparing the data for the two projects in spring, 2018 may be more instructive, although the change noted is smaller, in part because the student performance had already improved significantly. We hypothesize that the Cargill coaching is the responsible for most of the improvement noted between these two project. Students had already completed the safety course by the time the AICHE design project was turned in (last day of class was March 8, 2018), so it is doubtful that it is responsible for this increase. While faculty feedback on the design reports may have played a role, the students would have already received feedback on one report so the impact of more feedback would probably not have been as significant. We hypothesize that the opportunity to be coached in HAZOP analysis by the Cargill safety coaches improved students understanding and capability to address process hazards analysis. The improved performance on the safety aspects of the design reports and improved student assessment of their own ability to perform HAZOP analysis both support this hypothesis.

Conclusions

A university-industry collaboration was started between Kansas State University and Cargill to enhance students understanding of process safety. Cargill safety coaches interacted with student design teams throughout the capstone design course, most significantly by introducing concepts such as inherently safer design and RAGAGEP early in the design and leading the students through a HAZOP analysis of the potential hazards for their final design solution. It was found that student performance on analyzing process safety hazards improved between design projects in the fall and spring semester, and between the two design projects completed in the spring semester. This was attributed to the interactions between the design team and the Cargill safety coaches. A student survey supported this hypothesis, as the student response on their ability to conduct a HAZOP analysis showed a statistically significant increase from the beginning to the end of the semester.

References

Anonymous (2018), "Safety and Chemical Engineering Education". https://www.aiche.org/ccps/community/technological-communities/safety-and-chemical-engineering-education-sache

Center for Chemical Process Safety, Environmental Protection Agency, NOAA's Office of Response and Restoration, The Materials Technology Institute, Dow Chemical Company, Dupont, Phillips (2018), "Chemical Reactivity Worksheet". https://www.aiche.org/ccps/resources/chemical-reactivity-worksheet-40

U.S. Chemical Safety and Hazard Investigation Board (2009), T2 Laboratories, Inc Runaway Reaction Investigation Report, US Report No. 2008-3-I-FL