THE 2023 TIMEPOINT IN THE DEVELOPMENT OF PROCESS SAFETY EDUCATION

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INTRODUCTION

The Education Division Course Survey Committee completed its first ever survey dedicated to process safety education in Spring 2023. This paper reviews the history of undergraduate process safety education in the US both generally and through course and curriculum surveys conducted by AIChE's Education Projects Committee and later by the Education Division Course Survey Committee. The purpose is to elicit the trend of process safety education over time. The paper then presents results from the Committee's Spring 2023 survey focused on process safety education.

BACKGROUND

The AIChE Education Projects Committee Surveys from 1965 to 1993 asked very little about process safety.[1] "Plant safety" and "safe products" were mentioned as professional concepts in the 1972 survey over material balances, but "process safety" was not in the "list of criteria used by engineers to make decisions." In 1975, 1980, 1985, 1989, and 1993, "stability" was mentioned in process control surveys and "environmental science/engineering" appeared in electives surveys. In a change, "safety" and "reactor safety conditions" were requested as additional textbook topics for material and energy balances in 1990, and kinetics and reactor design in 1991. The emerging faculty interest in the early 1990s for safety content lagged industrial concern for process safety after the Bhopal disaster (1984) and the establishment of the Center for Chemical Process Safety (CCPS) in 1985.

The Education Projects Committee stopped surveying after 1993. The newly formed AIChE Education Division resumed curriculum and course surveys again in 2009. In the timeframe overlapping the end of the Education Projects Committee and the start of the Education Division, several things happened that gradually shifted the process safety education scene in the United States, as described in Figure 1. A longer and more entertaining version of this history was presented by Daniel Crowl for the Oklahoma State University ConocoPhillips Lectureship.[4]

During the 14-year hiatus of course and curriculum surveys, materials were developed for teaching process safety, a community of faculty interested in process safety was created, some faculty received guidance for process safety education, and accreditation pressures related to process safety increased. As a reflection of this changed environment, many of the surveys since 2009[5] directly addressed process safety, as shown in Table 1. Process safety instruction generally increases as students move through the curriculum, with process safety content present in 12% of introduction-to-discipline first-year courses and in 97% of capstone design courses. Process safety coverage was in approximately two-thirds of courses in kinetics and reaction engineering, process control, and unit operations laboratories.

These AIChE Education Division surveys about individual courses, and even the curriculum survey of 2016, did not

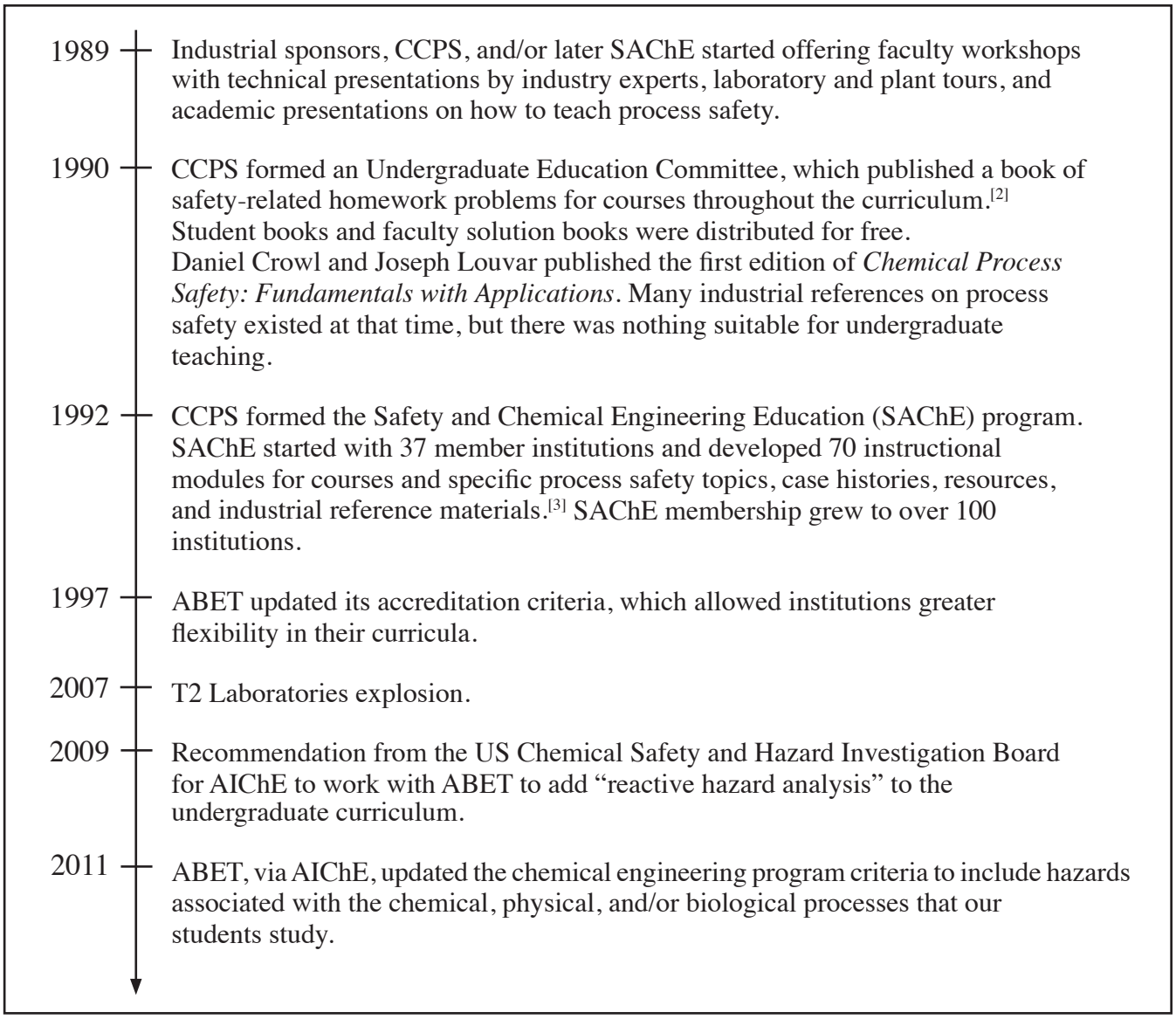

Figure 1. *Timeline of process safety education events (not to scale).*

address how process safety is being taught in a global way at each institution. Required, dedicated process safety courses have not been captured in any surveys. The survey in Spring 2023 was intended to address these knowledge gaps.

Surveys of process safety education in the US have been done by other groups. The Mary Kay O'Connor Process Safety Center surveyed departments twice about process safety education. In 2006, 21% of 102 responding departments required a process safety course (a core course) and 24% of responding departments had an elective process safety course.[6] The survey in 2012 showed an increase in required courses, with 27% of 106 respondents having a core process safety course.[7] Elective process safety courses remained essentially unchanged in 2012 at 23% of responding institutions. A different 2014 survey presented more detail about process safety education.[8] Required elective process safety course offerings again increased to 37% of 81 responding programs. Elective process safety courses declined to 9% of responding institutions. Of the 26 courses that reported credit hours, 31% were one credit hour; 23%, two hours; and 46%, three hours. The courses in these surveys from 2006, 2012, and 2014 were not captured in the Education Division surveys. Although the surveys in 2006, 2012, and 2014 give some historical data for comparison, they did not cover process safety in the depth typical of the Education Division Survey Committee Surveys.

As described above, the inclusion of process safety into the undergraduate chemical engineering curriculum has been gradual, with the result that most (77%) *CEP* readers responding to a 2021 survey felt they had not received

TABLE 1
Process Safety Mentions in Surveys from 2009 and Later Occur Throughout the Curriculum

Survey Year	Topic	Process Safety Mentions
2009	Freshman Experience	Mentioned three freshmen courses with safety content
2010	Reaction Kinetics	Courses at 74% of responding departments covered safety and runaway reactions, and 25% covered reactivity hazards.
2011	Material & Energy Balances	Safety, health, & environment was a topic in 64% of the courses at responding schools.
2012	Capstone Design	Reported on 13 elements of safety in capstone design, with flammability ranking highest at 64% of schools.
2013	Electives	*Safety* appears in the word cloud for "other" electives.
2014	Transport Phenomena	None
2015	Process Control	Safety was a process control topic for 63% of the respondents
2016	Curriculum	A department dropped a required course to replace it with a required process safety course.
2017	Unit Operations (UO) Lab	Identifying safety, health, and environment issues was represented in 45.9% of UO lab courses and directly assessed in 11.5%. Two-thirds of departments were addressing or trying to address process safety in lab.
2018	Thermodynamics	Twenty-six percent of programs used thermodynamics to discuss process safety: flash point, flammability limits, BLEVE, and pressure calculations for sealed vessels.
2019	First-year Experience	Twelve percent of the programs had process safety content in the first year. Safety courses (departmental or SAChE) were used in 10% of introduction to discipline courses. The most common change to introduction to discipline courses in the past five years was increasing process safety content (36% of courses).
2020	Kinetics and Reactor Design	Reactivity hazards were covered in 68% of courses. SAChE safety courses were used in 26% of kinetics & reactor design courses. Nineteen percent of the projects had a safety and health aspect.
2021	Material & Energy Balances	Making connections to both industry and process safety in the course was seen as an instructor role for more than 50% of the institutions. Seven percent of courses used a SAChE safety module. Safety, health, & environment was a topic in 48% of first MEB courses and 46% of second MEB courses.
2022	Capstone Design	Process safety was covered in capstone design by 97% of respondents, and occupational safety by 79%.

adequate process safety education as undergraduates.[9] Forty percent of the readers reported receiving no process safety education as undergraduates, 37% had less than one semester, 14% had one semester, and 3% had two semesters or more. The readership is an integration over time of chemical engineering undergraduate education, with some readers graduating recently and some many decades before. Responses were not broken out by when the respondent graduated, so it is unknown if engineers educated more recently received more education or were more satisfied with their process safety education.

The focus of this paper is the state of process safety education in the US and Canada, but the development of process safety education worldwide has been similar. Other recent articles review process safety education worldwide [10] and in France,[11] present student perceptions of two different process safety education methods in London,[12] and present student and faculty perceptions of a Columbian chemical engineering curriculum.[13]

METHODOLOGY

The process safety survey was conducted through Qualtrics® from February 2023 through May 2023. Messages announcing the survey were posted in the AIChE Education Division newsletter and department heads listserv as well as the ASEE Chemical Engineering Division newsletter.

Committee members sent personal email messages to faculty in their networks to request responses. When duplicates from a university are included, 104 responses were received. Duplicates were handled by removing the earlier reply from the same person or by deleting the less complete or elaborate response from the same institution. In one case, the information from both responses was combined. A total of 96 usable surveys were received from 95 institutions in the US and Canada.

The survey began with questions about the respondent's role at the institution, the undergraduate degree program title, and whether semesters, quarters, or trimesters are used at the institution. A question asked how process safety is taught: with safety lectures/problems/requirements in conjunction with coursework throughout the curriculum; with multiple required safety courses offered throughout the curriculum; in a single required safety course; in an elective safety course; and/or extracurricularly through AIChE membership. Programs with process safety content throughout the curriculum received a follow-up question about which courses contained process safety. Programs with one or more required process safety courses received follow-up questions about the number of credit hours for the required course, the year in which the required process safety course is usually taken, and which instructional materials were used. To understand the depth of student learning, all programs were asked to indicate the highest level of student comprehension (based on Bloom's taxonomy [14]) expected for ten process safety and nine management of risk learning outcomes in the curriculum overall. All programs were asked how many SAChE modules [15] were required in the curriculum. The survey concluded with open-ended questions about challenges particular to teaching process safety and distinctives about the process safety experience at the institution. Results are presented and discussed in the next section in the same order as presented here.

RESULTS AND DISCUSSION

A brief description of the respondents and their institutions is first. Respondents reported their roles at their institutions, and the majority (54%) were process safety instructors (N = 96). Respondents could choose multiple roles. Design instructors and lab instructors were both 38% of the respondents, with undergraduate directors at 26% and "other" at 12%. "Other" included department chairs, professors of practice, and safety specialists. Represented programs include chemical engineering (91%), chemical and varieties of bioengineering (7%), and biotechnical/biochemical engineering (2%) (N = 98 as two departments completed one survey covering two programs). Semester schools were 90% of the respondents, with quarter schools at 7%, trimesters at 2%, and other at 1% (N = 96).

Whether process safety should be taught in a dedicated course, embedded in many required courses, or both has been a subject of debate for 30 years.[16] A recent opinion piece came down strongly on the side of safety across the curriculum.[17] Respondents reported on where process safety was taught, with multiple selections allowed (N = 95). Available data from 2006,[6] 2012,[7] and 2014 [8] are included with the results from 2023 in Figure 2, but note that the 2006 and 2012 surveys did not ask about process safety throughout the curriculum. Most programs in 2023 cover process safety throughout the curriculum in many courses, but nearly half use one or more required process safety courses. The fraction of programs with required process safety courses has risen consistently since 2006 and more than doubled, while the fraction with elective process safety courses has declined to a lesser degree. The fraction of programs indicating they teach process safety with materials throughout the curriculum was larger in 2023 than in 2014. In both 2014 and 2023, more programs taught process safety in courses throughout the curriculum than with a required course.

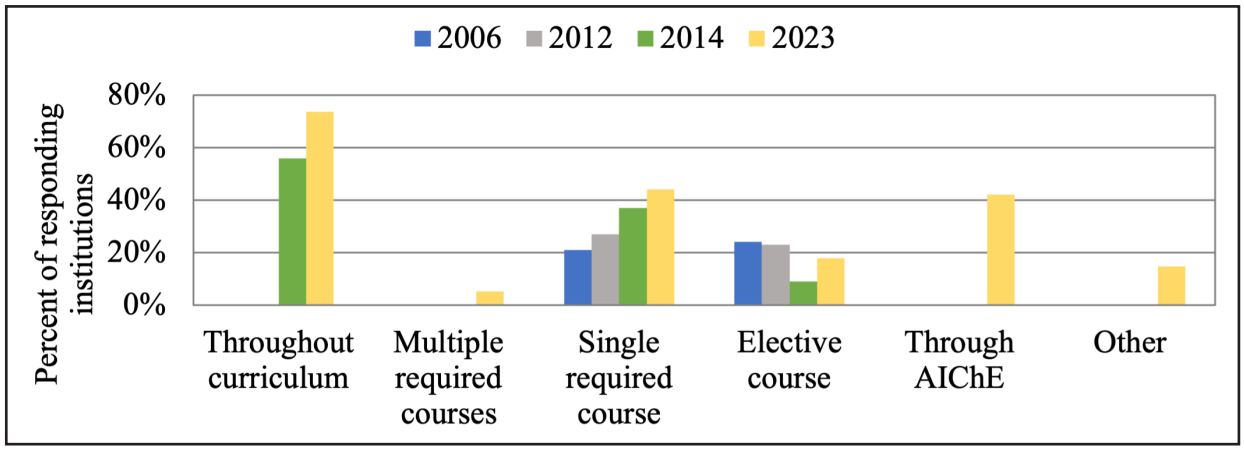

Figure 2. *Process safety was most commonly taught in many courses throughout the curriculum in 2014 and 2023.*

We cannot tell from the previous data how many departments used both a required process safety course and material throughout the curriculum. In the 2023 survey, 46% of respondents spread process safety across the curriculum only, 22% have a required process safety course only, and 22% teach process safety through both a required process safety course and in material throughout the curriculum.

Readers may be more interested in the number of students taught in a particular way than how many departments teach with that method. Another way of looking at these numbers is as a percentage of the 8697 US chemical engineering BS graduates in 2022,[18] which is an incomplete count of graduates. Students known through this survey to receive process safety education across the curriculum only are 24% of all graduates; with a required process safety course, 15%; and with both, 19%. Recast as a percentage of the 5571 graduating seniors represented in this survey, the percentages are 41%, 26%, and 33%, respectively. There is a slight correlation between the method of instruction and the size of the graduating class. Departments with a required course and content throughout the curriculum had the largest graduating class size: average 83 and median 73. Those with a required course alone had an intermediate class size: average 77 and median 63. Institutions with content throughout the curriculum only were the smallest departments: average 55 and median 49. Only the extremes, with required course and content throughout versus with content throughout only, were significantly different with a 1-tailed t-test ($p = 0.046$).

Only departments with process safety throughout the curriculum were asked which courses had process safety content (N = 69). Process safety content appears in four courses in over half of those departments: kinetics and reaction engineering, process control, free-standing laboratories, and capstone design (Figure 3). Students often see process safety in the material and energy balances course, but they are less likely to see it in thermodynamics, transport phenomena, or separations. The survey did not include first-year courses as a category, but a few faculty added it and other courses in the "other" category. Historical data from the most recent course surveys (Table 1) are included for comparison. Missing bars in the historical data trend means that either a survey does not exist for that course or process safety was not asked about in that course survey. When there were multiple surveys over the same topic, the historical data were averaged over the surveys. Considering the difference between the individual course surveys and this survey, and that the responding departments are different for each survey, the agreement between the historical data and this survey is very good. This agreement indicates the inclusion of process safety topics in these courses has been stable over the varied timeframes represented (all less than eight years).

There are a variety of instructional materials for process safety, and the use of these materials has increased over time. The 2023 survey asked "What resources are used to teach the required process safety course?". The 2014 survey asked a similar question about all process safety courses. CSB video[19] use increased with time from 68% to 89% of departments, textbooks from 53% to 83%, and SAChE courses[15] from 58% to 63%. SAFEChE: Process Safety Modules[20] were used in 15% of departments in 2023. The most popular textbooks in required process safety courses in 2023 that used a textbook (N = 38) were *Chemical Process Safety: Fundamentals with Applications* by Crowl and Louvar (89%)[21] and *Process Safety for Engineers* by AIChE CCPS (26%).[22]

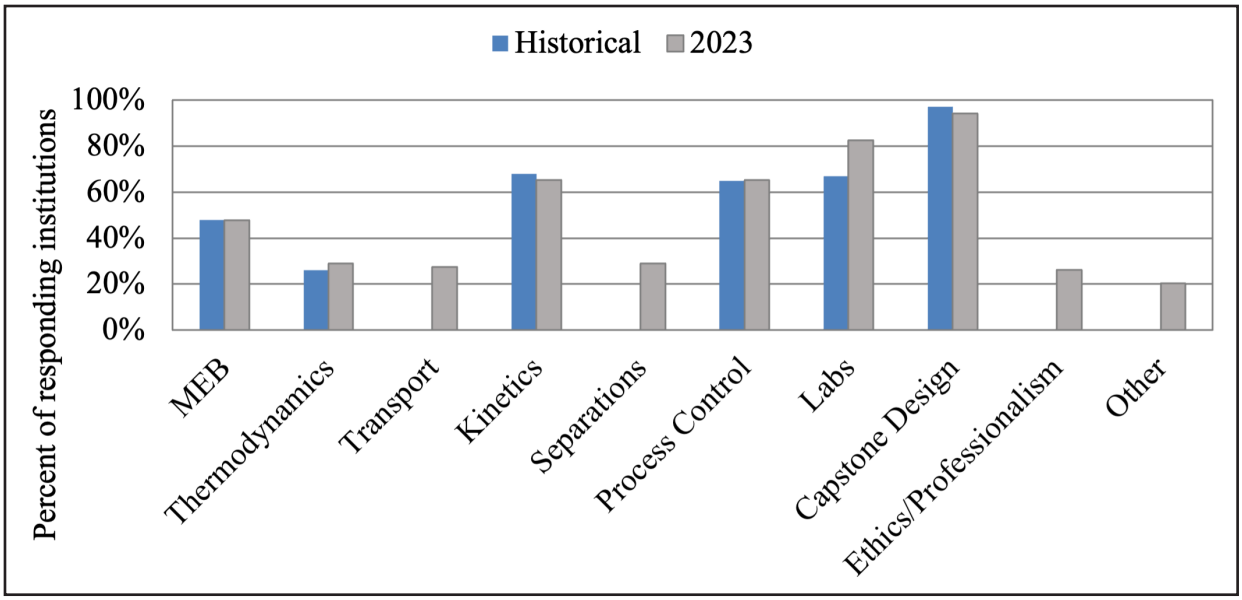

Figure 3. *Process safety is most commonly included in typical junior and senior courses.*

Another resource similar to CSB videos is Ramin Abhari's graphic novels related to process safety incidents.[23]

The number of credit hours for a required process safety course and when it is taken are reported next. A single required process safety course is typically three credit hours in the fourth year. Details about required courses were reported by 42 institutions. Reported credit hours were 19% of institutions with one credit hour; 14%, two hours; 62% three hours, and 5%, four hours. The quarter and trimester schools with a required course all reported three-credit-hour courses. Only one department clearly described multiple, required process safety courses, so multiple required process safety courses are not discussed in the rest of this paper. The single required process safety course is in the second year for 5% of departments; third year, 33%; fourth year, 64%; and fifth year, 10%.

Students see process safety content in several courses and/or a required process safety course, but what are they expected to know about process safety? Faculty were asked about the highest level of knowledge expected in the curriculum overall for process safety skills. In Figure 4, the results are broken down by how process safety instruction is done: in courses throughout the curriculum only (44 institutions), in a single required process safety course (21), or in both courses throughout the curriculum and a single process safety course (21). Blank space above the bars indicates the percentage of schools that expect no level of understanding of that skill.

In moving in Figure 4 from the left graph (in courses throughout only), to the middle graph (in a single required course only), to the right graph (both), these trends appear:

- More institutions expect any level of learning outcome (less blank space above the bars)
- More institutions expect higher levels of learning outcomes (shorter remember/understand bars, taller create/evaluate bars)

That using both a required course and content throughout the curriculum correlates with more departments expecting higher learning outcomes is not surprising, as there is more time overall available for instruction. The lower expectations for institutions with content throughout the curriculum than those with a required course alone was unexpected, as departments could set similar expectations for both instruction methods. Across all three types of institutions included in Figure 4, students were expected to know the least about codes and standards (column 2) and were expected to have the deepest learning outcomes for hazards identification (column 3) and process hazard analysis (column 4).

A similar question was asked about the highest level of management of risk learning outcomes expected in the curriculum overall. Results for management of risk outcomes

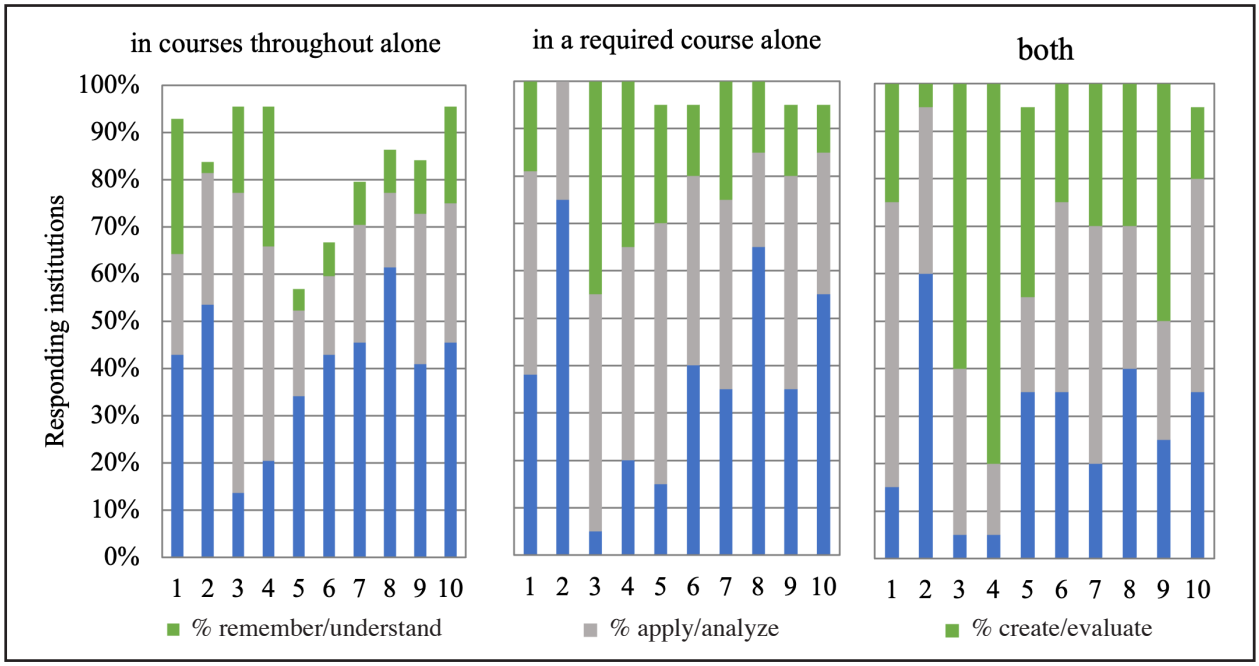

Figure 4. *Expected levels of learning outcome for process safety skills for the overall curriculum as reported by percentage of institutions with three types of process safety instruction. 1 = inherently safer design, 2 = codes and standards, 3 = hazards identification, 4 = process hazard analysis, 5 = consequence analysis, 6 = frequency/likelihood estimation, 7 = risk analysis, 8 = reduce risk (LOPA), 9 = pressure relief, and 10 = process control.*

are in Figure 5, which is arranged in the same way as Figure 4. The same pattern is seen with the management of risk learning outcomes as was seen with process safety skills. Institutions without a required process safety course were less likely to expect any level of learning outcome than those with a required safety course. In general, students are expected to have lower levels of learning outcomes for management of risk skills (Figure 5) than for process hazard safety skills (Figure 4). When all of the departments are combined, institutions expect the highest skill levels in personal protective equipment (column 2) and historical incidents (column 7).

The survey committee had a particular interest in the use of SAChE modules,[15] so the survey asked how many of the 36 SAChE courses existing in 2022 were required by each department. No courses were required by 37% of departments; 1 – 5 courses, 34%; 6 – 15, 20%; and 16 or more, 9% (N = 94). There was not a statistically significant effect of graduating class size on the number of SAChE modules required. These categories were chosen because there are five Level 1 courses and eleven Level 2 courses, making a total of sixteen Level 1 and 2 courses. Assuming that departments might require more lower-level SAChE courses was supported by data from SAChE, which show that the five Level 1 courses accounted for 36% of all SAChE courses completed in 2022. A second group of thirteen courses consisted of all eleven Level 2 courses and two Level 3 courses, Inherently Safer Design and Using Layer of Protection Analysis. This group of thirteen courses made up the next 45% of all SAChE courses completed in 2022. The remaining eighteen Level 3 courses were not frequently taken, as they were only 19% of all SAChE courses completed in 2022.

Faculty responded in the survey to an open-ended question about challenges in teaching process safety, and those results are categorized in the next several paragraphs. Of the respondents whose program did not contain a required standalone process safety course, 24 commented in various ways about the difficulty of fitting process safety into the chemical engineering core, with nine of these specifically mentioning capstone design and eleven specifically mentioning "credit limitations." The comments presented here and later were selected to avoid repetition. Comments included:

- "*Like so many other things, it makes most sense to do in capstone, which is already super crowded. That is the main place where different types of units come together to form a system, so the main place 'process' safety makes sense.*"
- "*There is little time in the curriculum. We are already being asked to cut ~15 credits from our curriculum.*"
- "*The curriculum is quite full and adding a required course, although desirable, is not practical.*"

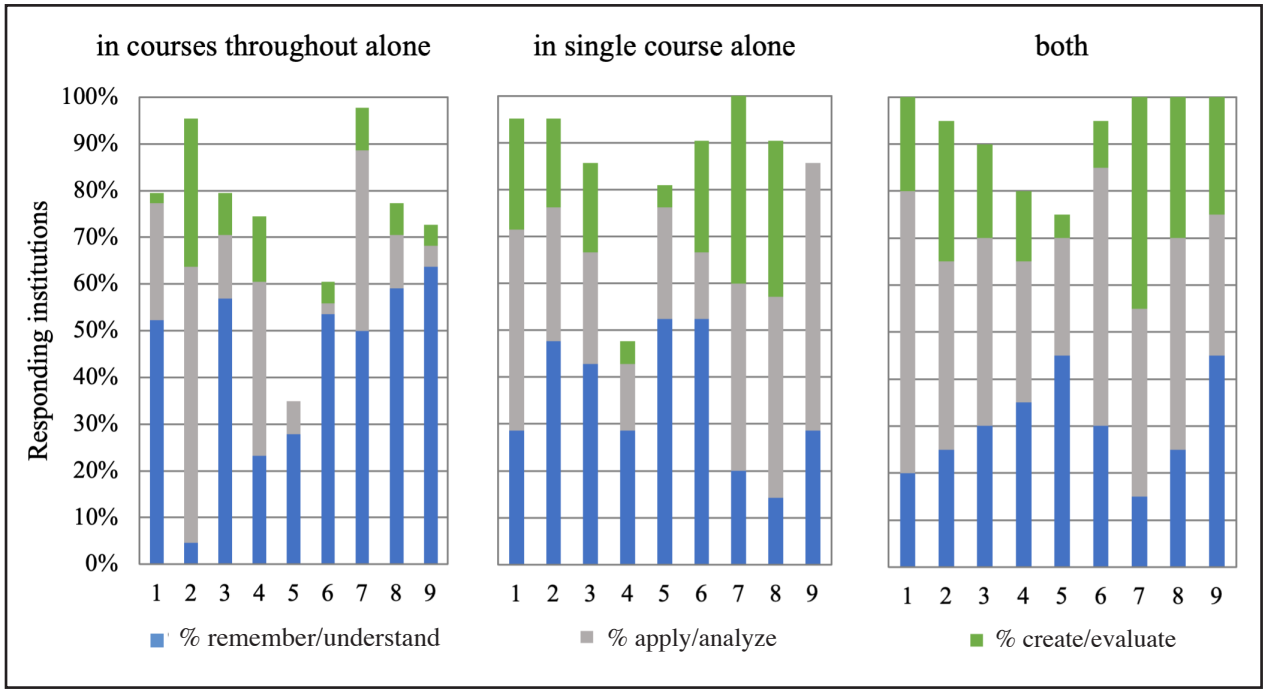

Figure 5. *Expected levels of learning outcome for management of risk skills for the overall curriculum as reported by percentage of institutions with three types of process safety instruction. 1 = risk management, 2 = personal protective equipment, 3 = safe work practices, 4 = instrument calibrated and appropriate, 5 = grounding and bonding, 6 = management of change, 7 = (historical) incidents, 8 = incident investigation, and 9 = emergency response.*

- "*Sometimes seems like safety is just 'added' rather than fully integrated into courses*."
- "*Most safety contents can be easily covered at the understanding level and at the apply/analysis level. Pushing the comprehension to the evaluate and create level would require much more lecture time and commitment which becomes challenging to many courses*."

However, the respondents whose program did have a standalone process safety course had their own various challenges related to the standalone course. Five respondents said fitting everything into a single course was a challenge, with responses such as:

- "*Hard to get into much detail in a 1-credit hour class that covers Safety, Health and the Environment as ours does*."
- "*Not enough time to cover as thoroughly as I would like*."

Seven respondents with required courses mentioned challenges associated with the availability of textbooks and other instructional materials for the standalone course, with:

- "*CSB resources [19] tend to be very high level and typically only document failures, without including any documentation covering what the company may have been doing well."*
- "*The biggest challenge has been to identify industrial PID's that could be used for HAZOP type projects*."
- "*There is a lot of information on hazard identification and risk assessment/analysis, but limited on risk mitigations/controls*."

Four other respondents noted significant challenges related to positioning of the standalone course in the curriculum, with comments such as these:

- "*As a junior level course, the students are still in a formative state for much of the subject matter, but it does definitely help contextualize their learning (in the other courses)*."
- "*Because the course occurs in the final term before graduation, it is difficult to integrate the material with our capstone design courses*."
- "*Teaching process safety requires prior knowledge and skills from the core chemical engineering courses, but at the same time needs to be taught prior to the capstone course. This makes it challenging to optimally place the course in our curriculum*."

And six respondents raised challenges in staffing a required process safety course, with comments including:

- "*Lack of industrial experience by the faculty and reluctance of industry to share meaningful examples*."
- "*Like it or not, most students consider the topic 'boring'. Further, most faculty are not eager to teach such a course*."

The comments from faculty about the challenges in staffing a process safety course have not changed since 1990, according to our senior co-author (DAC), even though we demonstrate in this paper that many more resources and professional development opportunities are now available for faculty compared to previous years.

However, the importance of the industrial context of process safety, and the lack of industrial experience for many faculty, are not confined to the specific question of who will teach the process safety course if there is one. There were about 20 additional responses to the question about challenges in teaching process safety that were related to the industrial context of the topic in various ways, and these came from respondents who both did and did not have a standalone process safety course. Some simply noted the desirability of incorporating an industrial point of view when addressing the topic:

- "*Most of our instructors do not have much industry experience (if any), so we often find that guest lecturers from industry are better able to connect the content to real world experience*."
- "*The faculty has little awareness of industrial practice. Anything that is design/safety related is dependent on industry professionals for the instruction*."

Since industrial experience was considered by the respondents to be an important factor in teaching process safety, we investigated their industrial experience. The survey did not ask about industrial experience of the faculty, but LinkedIn® profiles and faculty webpages were used for respondents who listed a role as process safety instructor in their survey responses to determine industrial experience. Work history is part of publicly available LinkedIn profiles, and neither of these web resources may accurately reflect their work history. Of the 44 departments that teach process safety only in courses throughout the curriculum, only 12 respondents listed themselves as process safety instructors. Many more of the respondents from institutions with required safety courses understandably listed themselves as process safety instructors: 19 of 21 institutions with a required course only and 17 of 21 institutions with a required process safety course and process safety in courses throughout the curriculum. We were unable to find an employment history for one professor each in the last two categories. Industrial experience was categorized to match the Committee's capstone design survey. [24] The results are shown in Figure 6. More of the faculty teaching process safety throughout the curriculum only have industrial experience than those teaching in programs with required process safety courses. The faculty teaching process safety in the programs with required courses who

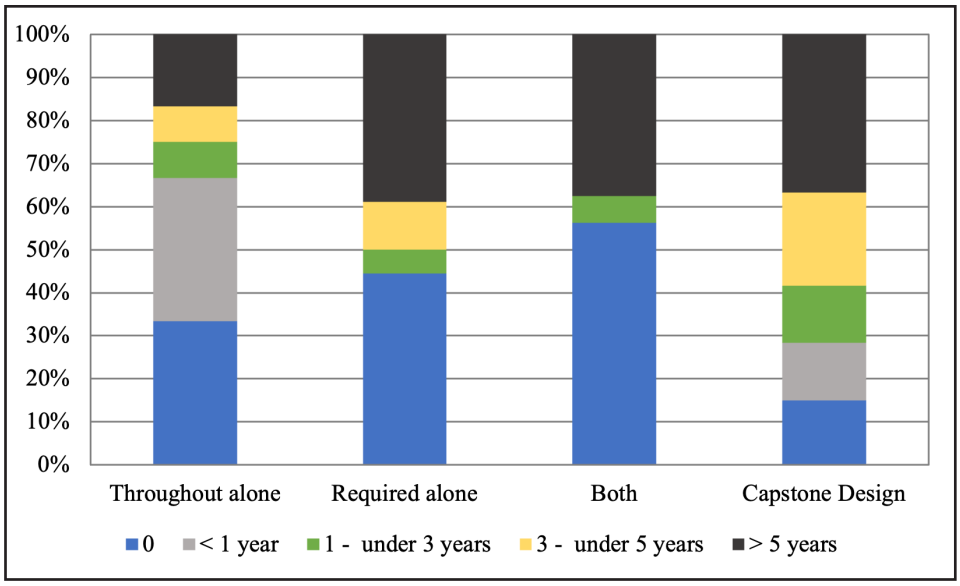

Figure 6. *Industrial experience levels of process safety instructors, broken down by how process safety instruction is provided, with data from the capstone design course survey.*

do have industrial experience; however, they typically have longer terms of industrial experience than those in programs with process safety throughout the curriculum only.

Capstone design is another course for which industrial experience is desired for faculty. From the capstone design course survey,[24] faculty teaching capstone design have similar levels of long (> five years) industrial experience as faculty teaching required process safety courses, but more faculty teaching capstone design have some industrial experience than faculty teaching process safety in the three methods of process safety instruction. Based on the experience levels of respondents, the concern about the lack of industrial experience of the process safety instructors is justified.

There are free ways for faculty to develop their process safety skills. SAChE modules are available to faculty for free if they email AIChE staff to ask for a promotional code (the current contact is Jing Chen at jingc@aiche.org). CCPS still offers free faculty workshops.[25] There are other modules available for both faculty and student training for a fee: Minerva Safety Management Education [26] and IChEME safety courses.[27]

Continuing with the responses to the open-ended question, other respondents noted challenges related to carrying out meaningful process safety instruction in an academic setting:

- "*It's hard to create environments where process safety can be taught then reinforced*."
- "*Contextualizing it and making it authentic to encourage student comprehension and long term learning*."
- "*Most of process safety (beyond design for safety) concerns plant operations. The curriculum does not teach students how to operate a plant. That is something to be taught by those who actually operate plants. Students learn this when they join a company and take up a job in plant operations. Without a credible plant situation, it seems doubtful that a course in a university will do a realistic or credible job in this facet of professional education*."

Finally, a number of respondents noted challenges stemming from the experience levels, and the plans and goals, of the students:

- "*The wide range of student experience makes it difficult for some students to understand risk vs. severity. Less experienced students seem to have a tendency to underestimate severity (maybe because they confuse it with risk) and risk*."
- "*We perform example HAZOP's and LOPA analyses in our curriculum, so the students are exposed to the concepts and get some practice, but they don't have the technical background (gained through years of industry experience) to really understand the cause and effect principles involved*."
- "*The students also don't know what they don't know. For instance looking at reverse flow in a pipe. Often, students can't think of a single way that could come about. This is partially due to a lack of experience as fluid flow theory, Bernoulli's equation, doesn't address ways reverse flow could happen*."
- "*We have a lot of students that do not go into the chemical process industry, and making this course relevant to them is challenging*."

- "*The body of knowledge is broad, deep, and highly technical for some areas of expertise. Sometimes the material requires more technical competence than the students have acquired.*"
- "*Some students tend to see process safety as a qualitative subject and may not immediately appreciate its importance. Other students may not connect with the material unless the instructor is able to personally relate with the content by talking about first-hand experiences.*"

When asked about distinctives for their process safety instruction, faculty tended to respond in four different categories.

- Having someone with industrial experience. There were many comments saying that the instructors themselves had industrial process safety experience or they had an industrial mentor involved. Separately, there were many comments about the benefit of having guest speakers with experience (even from other non-chemical fields such as bio or cybersecurity).
- Integration of technology/software that ranges from actual process safety management software (such as ioMosaic®, BakerRisk®, Phast™/Safeti™, etc.) to using ASPEN HYSYS® to other software such as the "Contents Under Pressure" video game.[28]
- Faculty mentioned weaving in other "moral" subjects into process safety education such as ethics, DEI topics, and sustainability.
- An "interesting" aspect was the addition of Process Safety Research for undergraduates, typically in departments/universities with dedicated Process Safety Research centers.

In their ending comments, faculty pointed out some important factors:

- Sometimes development of a safety culture is more important than technical development in the instruction.
- Case studies and ties to other courses are important.
- Process safety should be integrated into process design.
- Industry has a key role (speakers, tours, connecting courses to practice).
- Lab courses are an opportunity to apply HAZOP, What-if, FMEA safety analyses.
- There is still confusion between lab/personal safety and process safety topics.
- Faculty who do not teach dedicated safety courses and who lack industrial experience are often not motivated to learn about process safety.

SUMMARY

In this paper we have traced a recent history of process safety education. Process safety is taught in courses throughout the curriculum, in required safety courses, or both. We have shown an increase over time in the fraction of institutions with process safety content throughout the curriculum. Most often that content is in kinetics and reaction engineering, process control, free-standing laboratory, and capstone design courses. We have also shown an increase over time in the fraction of institutions with a required process safety course, which is most frequently a three-credit-hour course in the senior year. We documented the expected learning outcomes for both process safety and management of risk skills. Departments without a required process safety course require fewer skills than those with a required course, and those skills are at a lower level than those required at institutions with a required course. Faculty provided many comments about teaching process safety, including the challenges of teaching an industrially oriented subject without industrial experience. An industrial contact to assist in teaching process safety is a plus, and we include information about free resources available to faculty for their own professional development.

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