Analysis of the Use of SAChE Modules in Undergraduate Programs and Summary of Process Safety

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Analysis of the Use of SAChE Modules in Undergraduate Programs and Summary of Process Safety Panel Discussion

Abstract

A summary of the process safety education panel at the AIChE Annual Meeting will be presented and archived along with some re-analysis of survey data. The re-analysis showed that more institutions that require SAChE modules expect higher levels of student comprehension than institutions that do not require the modules. Ways to include everyday process safety considerations instead of focusing on explosions, to get faculty buy-in on process safety education, and to educate colleagues and ourselves on process safety were discussed. A list of process safety lab experiments was compiled.

Introduction

The AIChE Education Division (EdDiv) Course Survey Committee did a survey on process safety in spring of 2023. The survey was distributed through the EdDiv chairs listserv and email newsletters for EdDiv and ASEE's Chemical Engineering Division. Responses were also solicited by personal emails from committee members. A total of 96 usable responses from 95 institutions in the US and Canada were received. Results were presented at the AIChE Annual Meeting in 2023 [1], and a journal article is under revision [2]. A brief summary of the results is given here to avoid violating ASEE's plagiarism policy with an extensive literature review and results section. More departments teach process safety in material throughout the curriculum (74%) than in a single process safety course (44%), and both of those numbers have increased over time [3], [4], and [5]. Of the departments teaching process safety throughout the curriculum, more than half of them use kinetics and reaction engineering, process control, free-standing laboratories, and capstone design. When a single process safety course is required, it is most likely a three-credit-hour course (62%) in the fourth year (64%). Departments reported their expected comprehension levels for process safety and management of risk skills. Departments without a required process safety course required fewer skills than those with a required process safety course, and those required skills were at a lower level than those required at institutions with a required process safety course.

After the AIChE presentation of the survey results, we hosted a panel discussion about process safety topics. Four panelists were chosen to represent different ways of teaching process safety. Pennsylvania State University uses more than 16 SAChE modules in the curriculum and was represented by Gary Aurand. Christopher Barr is from the University of Michigan, and he manages the SAFEChE website for resources for teaching safety throughout the curriculum. Frank Bowman from the University of North Dakota was chosen to represent having process safety education in many different courses across the curriculum. Hema Ramsurn is from the University of Tulsa, where she teaches a required process safety course in the senior year.

This proceedings paper is divided into three sections. In the first section, we reanalyze the survey data with a focus on how many SAChE modules are required. The second section contains advice collected during the panel discussion. The third section lists some resources that were mentioned during the panel discussion.

New Analysis Regarding Process Safety Online Learning Modules

One question posed to the panel inspired us to go back and analyze the survey data from a new angle:

> Process safety is about design, which requires open-ended questions, discussion, case studies, iterative analysis, and analysis. Given this, how can the online, asynchronous [SAChE] modules really teach the students process safety?

The survey results included data about the use of SAChE modules, the expected comprehension levels for student learning outcomes, and whether process safety was taught throughout the curriculum and/or in a dedicated course. We reanalyzed the data to look at the use of SAChE modules by method of teaching process safety and the expected comprehension levels by number of required SAChE modules.

The first reanalysis question was whether schools that teach process safety in different ways rely on SAChE modules to different degrees. The three different ways of teaching process safety considered here are throughout the curriculum without a required process safety course ("throughout alone"), in a required process safety course alone ("required alone"), and throughout the curriculum with a required process safety course ("both"). The results are given in Figure 1. Starting at the bottom of the graph with zero required SAChE courses, institutions which have both a required course and process safety education throughout the curriculum have the smallest zero required column, so more of these institutions use SAChE modules than other institutions. These institutions also have the highest percentage of using only 1 – 5 modules, so many of these institutions use a few SAChE modules. Looking next at the columns for 6 – 15 and 16+ required SAChE modules, the institutions who have only a required process safety course rely more heavily on the SAChE modules: they have the highest percentage of institutions requiring 6 – 15 modules and the highest percentage requiring 16+ modules. Institutions teaching process safety throughout the curriculum alone are the most likely to require no SAChE modules, but they are intermediate in requiring the other categories. The use of SAChE modules decreases moving from required course alone (many institutions requiring many modules) to throughout the curriculum with a required course (many institutions requiring a few modules).

We also parsed the survey data to look at the highest expected level of student comprehension by how many SAChE modules were required. Figure 2 is set up such that each group of four columns represents one process safety learning outcome. The outcomes are given in Table 1. Within each group of four columns for an outcome, the number of SAChE modules required increases moving from left to right. The far left represents the 36 institutions with no SAChE modules required, the middle left is 27 institutions with 1 – 5 SAChE modules required, middle

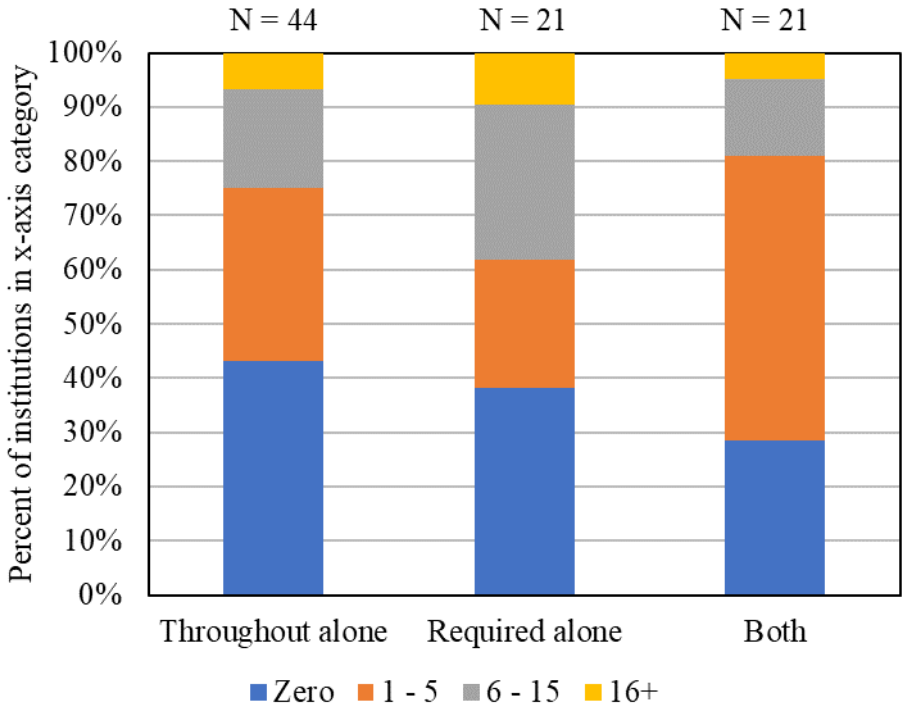

Figure 1. SAChE module requirements by how process safety is taught: throughout the curriculum without a required process safety course (throughout alone), in a required process safety course only (required alone), and throughout the curriculum with a required process safety course (both)

right is 19 institutions with 5 – 16 SAChE modules required, and the far right is 8 institutions with 16+ required SAChE modules. Given how few institutions are in the category of 16+ SAChE modules, the uncertainty in the values for the far-right column is quite high. This category is included in the graphs but is not discussed. Departments chose the highest expected level of comprehension from none expected, remember/understand, apply/analyze, and create/evaluate.

Figure 2 shows the percentage of departments that had no expectation of any level of student comprehension for the process safety learning outcomes grouped by the number of required SAChE modules. For process safety learning outcome 5, there is decrease in the percentage of departments having no expectation of student comprehension moving from no required SAChE modules to 1 – 5 required to 6 – 15 required. For process safety learning outcomes 2, 6, 8, and 9, there is a similar decrease from no required SAChE modules to 1 – 5 required. Learning outcomes 4 and 7 have an increase in no expected comprehension in moving to 6 – 15 required modules, and the remaining learning outcomes do not show a trend. Overall, a smaller percentage of departments requiring 1 – 5 SAChE modules have no expectations of student comprehension than those departments requiring no modules.

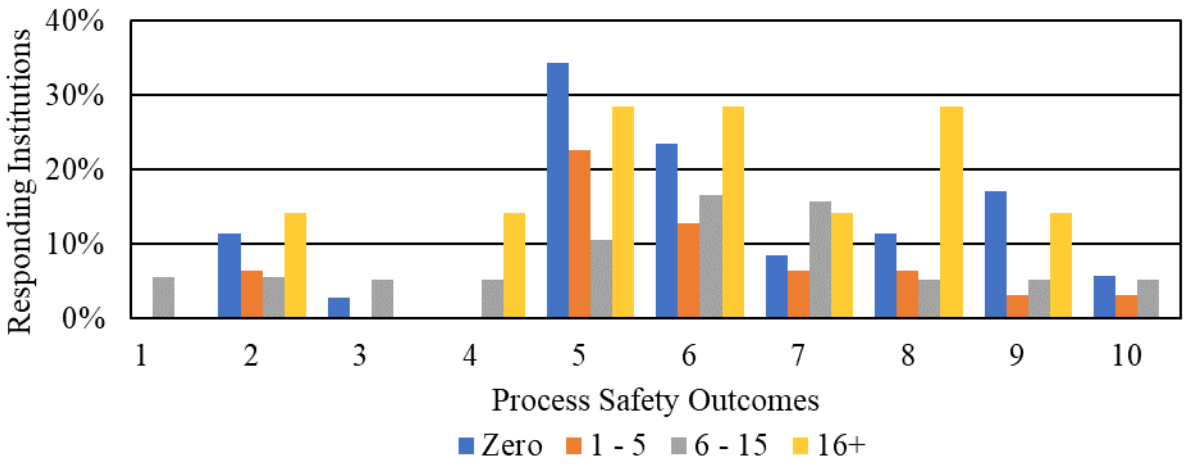

Figure 2. Percent of departments which expect *no level* of student comprehension for *process safety* learning outcomes (listed in Table 1) by required number of SAChE modules. Within each topic cluster, far left = zero SAChE modules (N = 36), middle left = 1 - 5 modules (N = 27), middle right = 6 - 15 modules (N = 19), and far right = 16+ modules (N = 8)

Table 1. Outcomes analyzed by expected level of student comprehension.

Outcome	Process Safety
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
10	process control

Figure 3 presents similar survey results for the remember/understand expected level of student comprehension for process safety outcomes. For outcomes 1 and 8 there may be a decrease in institutions expecting this level of comprehension in moving from no required SAChE modules to 1 – 5 required to 6 – 15 required. For outcome 2, there is a decrease in moving from no required modules to 1 – 5 required modules. For outcomes 3, 4, and 6, more institutions requiring 1 – 5 modules expect the remember/understand level than institutions requiring no or 6 – 15 modules. For the rest of the outcomes, the number of modules from zero to 15 does not affect the expected comprehension level.

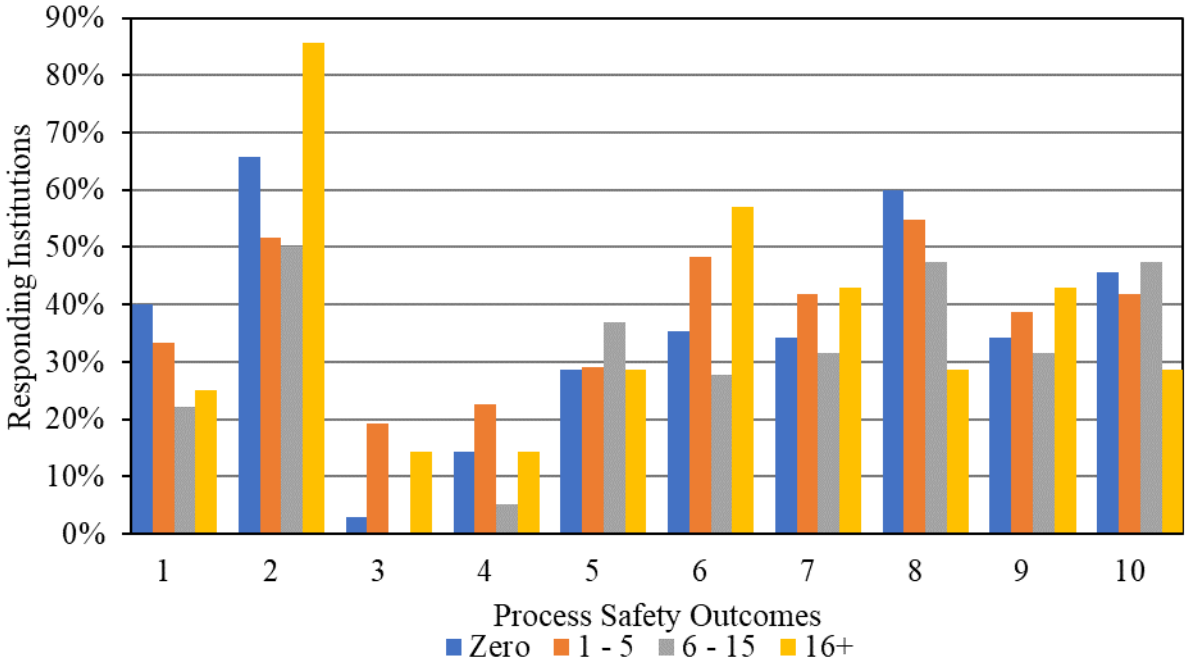

Figure 3. Percent of departments which expect the *remember/understand* level of student comprehension for *process safety* learning outcomes by required number of SAChE modules.

Figure 4 presents the same data for the apply/analyze expected level of student comprehension for process safety outcomes. For outcomes 5 and 9, there is an increase in institutions expecting this level of student comprehension moving from no required SAChE modules to 1 – 5 required to 6 – 15 required. For outcomes 1, 2, and 10, there is an increase in institutions expecting this level moving from no required modules to 1 – 5 required. There is a decrease in institutions expecting this level for outcome 3 in moving to more required modules. For outcomes 6 and 8, more institutions requiring 6 – 15 modules expect this student comprehension level than institutions requiring fewer modules. Overall, there is an increase in institutions expecting the apply/analyze level of student comprehension moving from no required SAChE modules to 1 – 5 required modules to 6 – 15 required modules.

Figure 5 presents the survey data for the create/evaluate expected student comprehension for process safety outcomes. Four outcome 3, more than double the fraction of institutions requiring 6 – 15 SAChE modules expect the create/evaluate student comprehension level than institutions requiring fewer modules. For outcome 4, more institutions requiring 1 – 5 and 6 – 15 modules expect this student comprehension level than those requiring none. For outcomes 5, 9, and 10, fewer institutions expect this level moving to 6 – 15 required modules. The net effect of requiring more SAChE modules on the percentage of institutions expecting the create/evaluate level of student comprehension may be a wash.

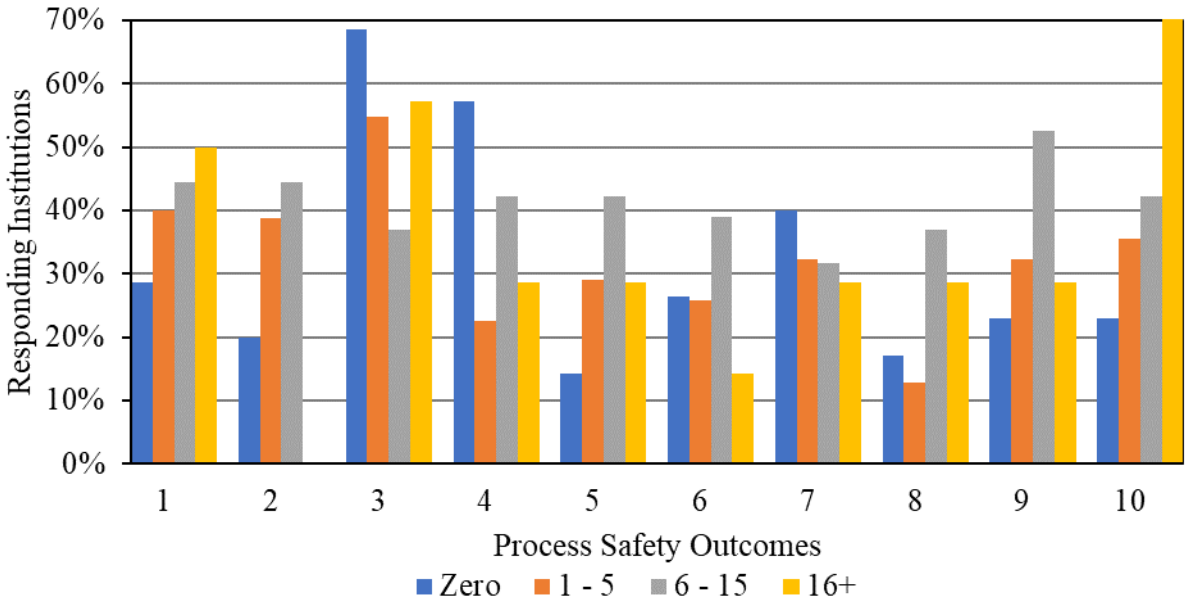

Figure 4. Percent of departments which expect the *apply/analyze* level of student comprehension for *process safety* learning outcomes by required number of SAChE modules.

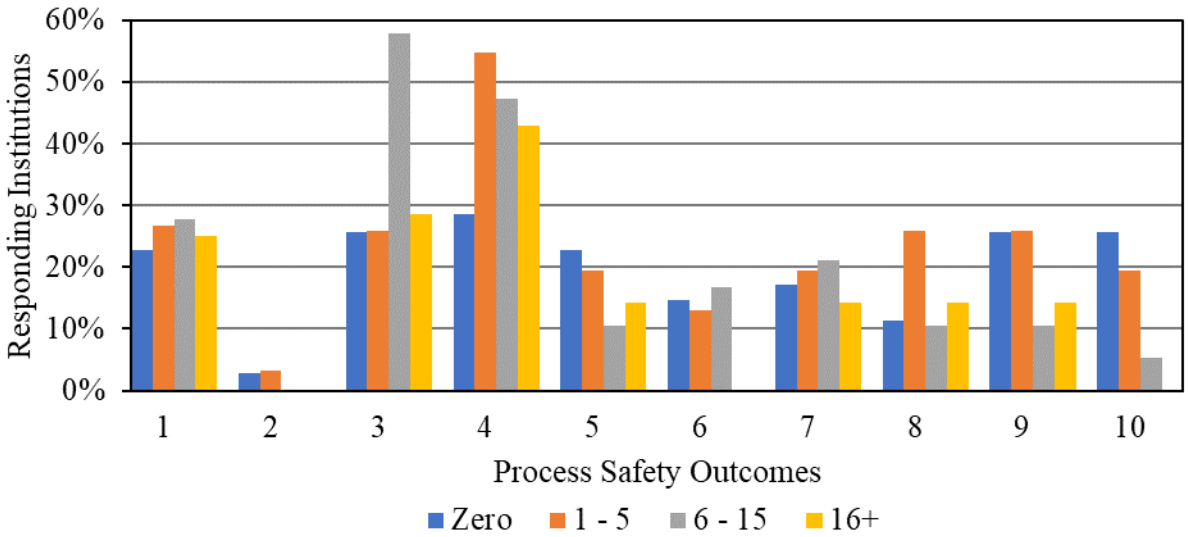

Figure 5. Percent of departments which expect the *create/evaluate* level of student comprehension for *process safety* learning outcomes by required number of SAChE modules.

We might like to say that moving from no expected level of student comprehension to remember/understand and onward to apply/analyze and create/evaluate is desirable, but this will depend on each institution's constituents, its educational program, and each particular learning outcome. Here we will consider the higher levels of student comprehension to be desirable. An average delta function was defined in Equation 1 to find the change in percentage of institutions expecting a particular comprehension level from that of institutions requiring no SAChE modules.

$$\Delta_i = \frac{\sum_j (P_{i,j} - P_{none\ required,j})}{N} \quad (1)$$

where Δ_i = the average delta function for the *i* category of SAChE module requirements,
P_i = percentage of institutions in the *i* category of SAChE module requirements,
j = learning outcome, and
N = number of learning outcomes.

The average delta functions for process safety learning outcomes are presented in Table 2. Compared to institutions requiring no SAChE modules, institutions requiring 1 – 5 modules have fewer process safety learning outcomes at the no expected comprehension level and possibly (given data uncertainty) more at the create/evaluate level. Institutions requiring 6 – 15 SAChE modules have a shift from no expectations and the remember/understand comprehension level to the apply/analyze level.

Table 2. Average delta functions for process safety learning outcomes.

	Required Number of SAChE Modules		
Comprehension Level	1 - 5	6 - 15	16+
None	-6.2%	-4.3%	1.9%
Remember/Understand	2.1%	-6.1%	0.7%
Apply/Analyze	0.6%	9.4%	1.8%
Create/Evaluate	3.6%	1.0%	-4.4%

The results for highest expected level of student comprehension for management of risk learning outcomes by number of required SAChE modules are shown in Figures 6 – 9 with the outcomes listed in Table 3 and the average delta functions in Table 4. Focusing again on only the first three columns, Figure 6 shows that a lower percentage of institutions expect their students to have any level of comprehension for outcomes 1, 3, 4, 5, and 6 as the number of required SAChE modules decreases.

Table 3. Outcomes for Management of Risk

Outcome	Management of Risk
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
9	emergency response

Figure 7 shows that more institutions requiring 1 – 5 SAChE modules expect the remember/understand student comprehension level than institutions requiring no modules or 6 – 15 modules for outcomes 1 and 8. About twice as many institutions requiring 6 – 15 modules than other requirements expect this level for outcome 5. The percentage of institutions expecting the remember/understand comprehension level decreases with more required SAChE modules for outcome 7, and for outcome 3 institutions requiring no modules expected this level more than institutions requiring SAChE modules. Outcome 9 shows a slight increase in institutions expecting this level with required modules.

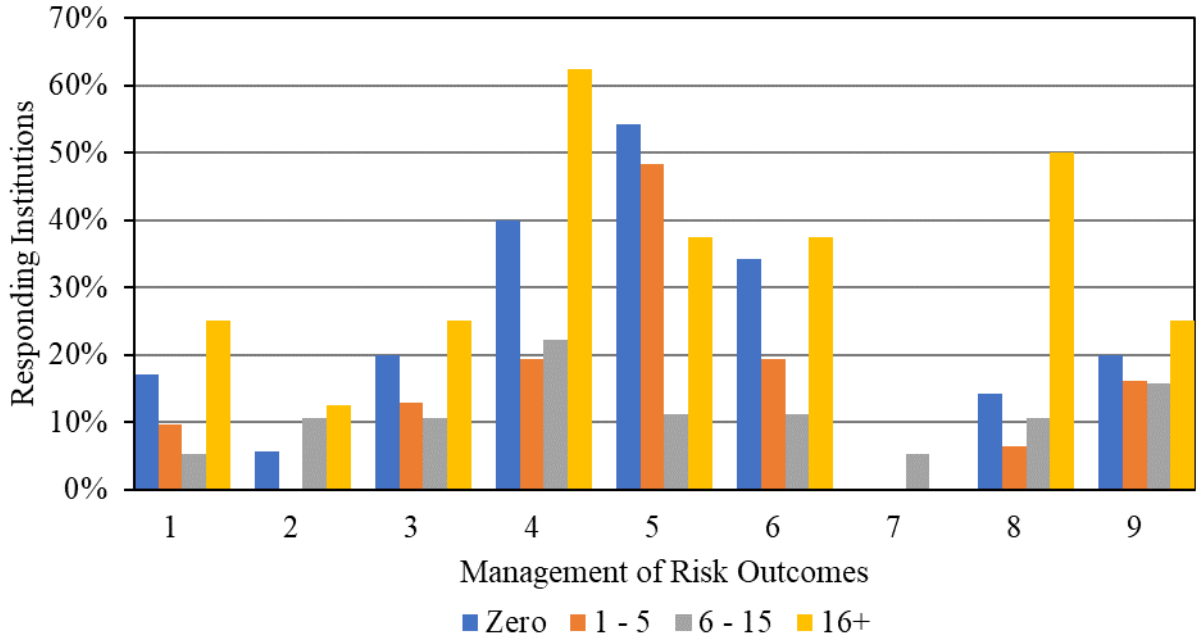

Figure 6. Percentage of institutions expecting *no level* of student comprehension for *management of risk* learning outcomes (in Table 4) by required number of SAChE modules. Within each topic cluster, far left = zero SAChE modules (N = 36), middle left = 1 - 5 modules (N = 27), middle right = 6 - 15 modules (N = 19), and far right = 16+ modules (N = 8)

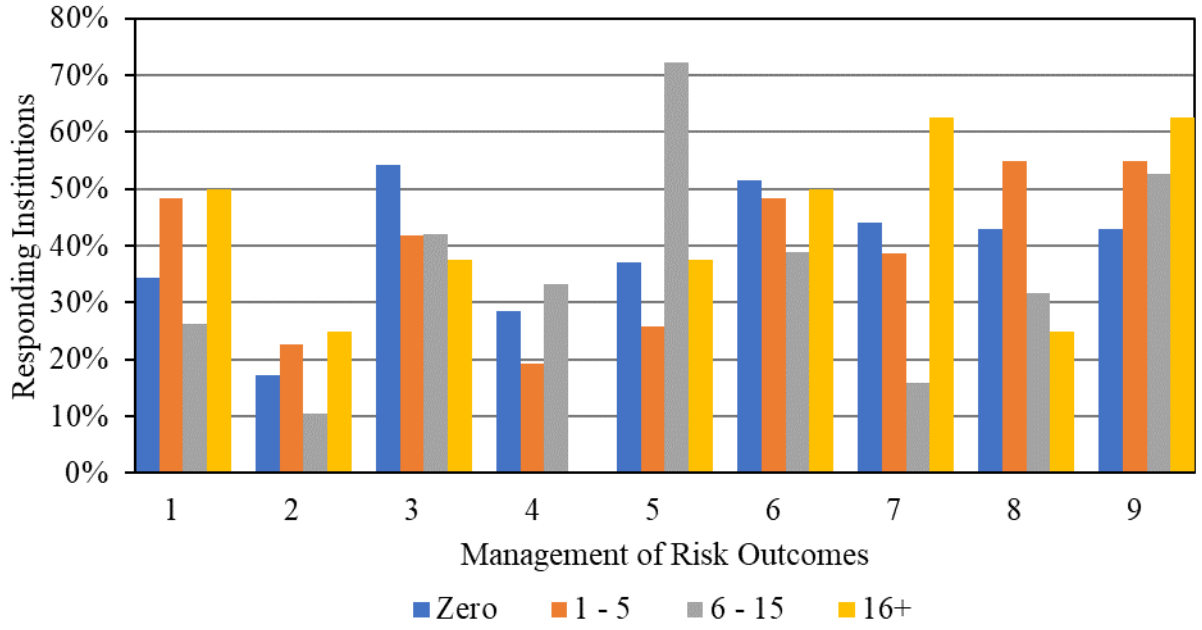

Figure 7. Percentage of institutions expecting the *remember/understand* student comprehension level for *management of risk learning* outcomes by required number of SAChE modules.

Figure 8 presents the data for the apply/analyze expected level of student comprehension for management of risk outcomes. There is an increase in the percentage of institutions expecting this level with more required SAChE modules for outcomes 3, 6, and 7. More institutions that require 1 – 5 and 6 – 15 modules expect this comprehension level for outcomes 4 and 5 than institutions that do not require modules. For outcomes 1, 8, and 9, there is a dip in institutions expecting this level at institutions requiring 1 – 5 modules.

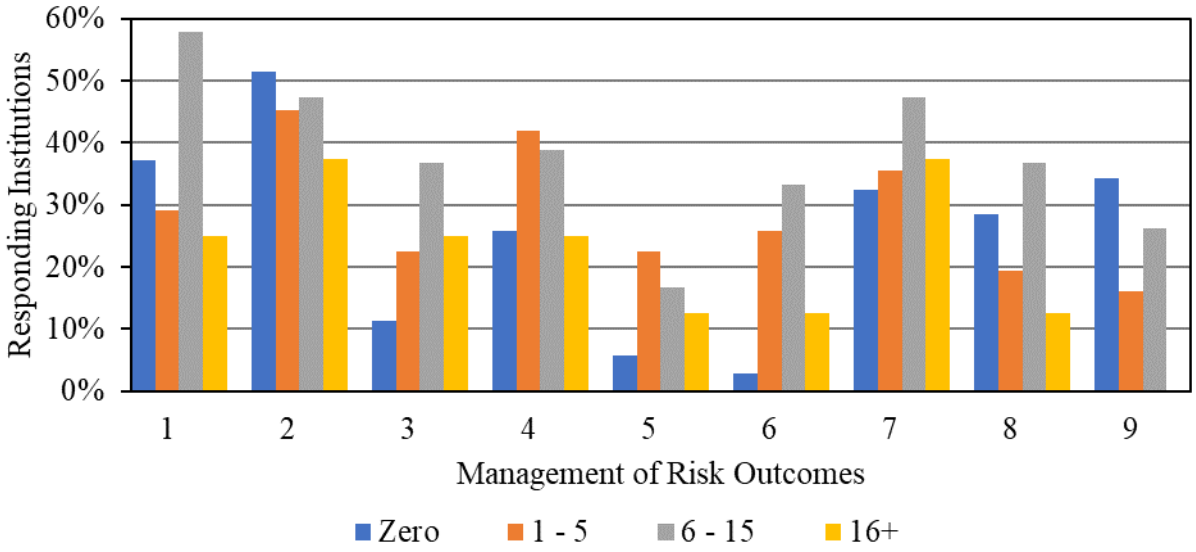

Figure 8. Percentage of institutions expecting the *apply/analyze* level of student comprehension for *management of risk* learning outcomes by required number of SAChE modules.

Figure 9 shows that more institutions requiring 1 – 5 SAChE modules expect their students to have the create/evaluate level of student comprehension than institutions requiring fewer or more SAChE modules for management of risk outcomes 3, 4, and 9. There may be an increase in institutions expecting this level of student understanding for outcomes 7 and 8 in moving toward more required modules. Other outcomes do not show a clear trend.

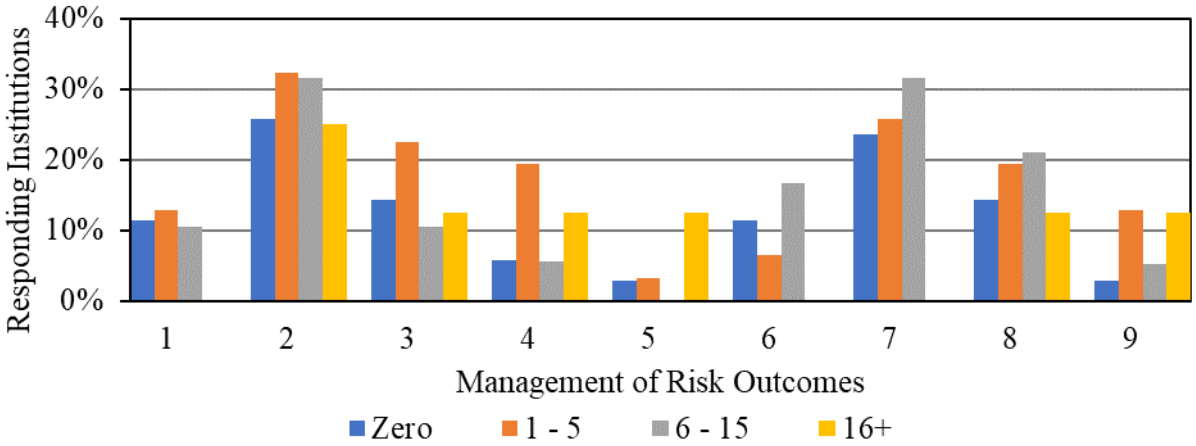

Figure 9. Percentage of institutions expecting the *create/evaluate* level of student comprehension for *management of risk* learning outcomes by required number of SAChE modules.

The average delta functions for management of risk learning outcomes are presented in Table 4. When compared with institutions that require no SAChE modules, a smaller percent of institutions that require 1 – 5 SAChE modules expect no comprehension level and a higher precent expect the create/evaluate level. A smaller percent of institutions that require 6 – 15 modules expect no comprehension level and a higher percent expect the apply/analyze level.

Table 4. Average delta functions for management of risk learning outcomes.

	Required Number of SAChE Modules		
Comprehension Level	1 - 5	6 - 15	16+
None	-8.2%	-11.5%	7.7%
Remember/Understand	0.2%	-3.3%	-0.3%
Apply/Analyze	3.2%	12.4%	-4.7%
Create/Evaluate	4.7%	2.3%	-2.7%

When the results in Tables 2 and 4 are combined, more institutions that require SAChE modules have higher expectations of student comprehension than institutions that do not require the modules. To respond indirectly to the question posed to the panel, perhaps the institutions use the SAChE modules to introduce material so course time may be spent on reaching the higher levels of student comprehension.

The question regarding online learning modules versus interactive learning for higher student comprehension levels in process safety generated discussion with the panel and the audience. By the time they graduate, what level of comprehension should the students attain? Different industries have different expectations. There should be a general understanding that universities start with the students off in process safety but that industry will train them in what they need to know specifically. For example, graduates should recognize when pressure relief is needed but not necessarily know how to do the sizing of the relief valve. Students should learn how and when to ask questions about process safety so that they can learn on the job. Process safety will be part of their lifelong learning. Most industry is glad that the students have awareness of process safety after graduates had little to no process safety training for so many decades.

As accrediting bodies require, departments must periodically review their program educational objectives, student outcomes, and educational efforts. These include outcomes with process safety. The figures and tables above are provided so institutions may compare themselves to others during their reviews. We encourage faculty to consider the comprehension level of process safety and management of risk skills that they and their constituents expect of their students as well as the tools that they use to achieve these skills.

Advice from the Panel and the Audience for Teaching Process Safety

If you are interested in using SAChE modules in your courses, consider taking the courses yourself for free. Contact AIChE for your promo code (Jing Chen at jingc@aiche.org). Devote

some class time during the first week of class for the students to help each other become AIChE members and to get the modules purchased (for free) so that they are ready to do the modules on their own time. Post due dates for the modules but don't penalize the students for being late. Follow up with the students who are behind. If you let the students wait until the end of the semester to submit all of the documentation for the SAChE modules, then it's likely that you'll have academic misconduct (falsified certificates).

Getting faculty on board with teaching process safety across the curriculum can be a challenge. It is helpful to have a safety champion on the faculty. Another suggestion is to have a summer retreat to check that everyone is covering the process safety content that should be in their courses. At this retreat, remind faculty that they are building courses to fit into a department, not to their particular fiefdoms of research, and point out resources within the faculty to help each other. The faculty workshops offered by the Center for Chemical Process Safety are a good way to train faculty in new safety material. Another departmental good practice is having a regular process for reminding people who rotate into courses about the unstated, secret learning objectives for the courses. Better yet, make those secret learning objectives explicit at the summer faculty retreat. Co-teaching is another way to help faculty come on board with new material in their courses.

Once we have buy-in from the faculty, we must also get buy-in from the students. Many felt that students return from internships motivated to learn process safety, as students see at their internships that process safety is important to their companies. Have alumni talk with the students about the importance of process safety, particularly the importance in getting hired. For those who don't do internships, having a lab emphasis on process safety (not just lab safety) is important. The students can inspect the faculty's research labs to emphasize the importance of process safety to students. The students should train with the Environmental, Health, and Safety department on campus before they do the faculty lab inspections. Because some students are motivated by what is on the exam, put process safety on the exam. Another way to connect with alumni is to have the students present to alumni about process safety or lab inspections, and have the alumni talk about process safety at their workplace. Encourage the students to put the SAChE modules on their resumes under education or related coursework and mention them in their interviews.

Process safety can be a scary topic if we emphasize explosions and disasters. Emphasize instead that chemical engineering is about keeping people safe: we have a safety culture because we care about the students, the operators, and the employees. Teach successes as well as disasters and emphasize learning from failures and leading and lagging indicators. The Center for Chemical Process Safety is working on a project about successes - look for *Risk-based Process Safety – Implementation Guide* in mid-2025.

Another way to move from disasters is to focus on the daily practice of safety. Have the students do a hazard and risk analysis for walking into traffic without looking or for driving while on their

phones to bring process safety into their everyday lives. Emphasize incident reporting for labs, including near misses. A form is available on the SAFEChE website to use in your lab [6].

Other audiences on campus should be interested in process safety, too. Business majors can be pulled in with the story of Paul O'Neill turning Alcoa from unprofitable to profitable by focusing on safety culture [7], [8]. Process safety can be tied to ergonomics, economics, ethics, and project management. The Center for Chemical Process Safety has a document called the business case for process safety [9]. A safety course for non- chemical engineers will be different from a course for chemical engineers. At the University of Michigan, the safety course is open to non-chemical engineers. The course has a lot less math than in the Crowl and Louvar textbook and emphasizes toxicity and industrial hygiene [10].

Resources

Some faculty were interested in adding process safety experiments to their educational programs. The faculty listed here are willing to discuss the experiments in their departments. Greg Ogden (University of Arizona) presented at the AIChE Annual Meeting on hydro-proofing plastic bottles [11]. Tom Spicer (University of Arkansas) runs an experiment with the advanced reactive system screening tool (ARSST) [12]. David Murhammer (University of Iowa) studies flammability, ignition testing, dust explosions, electrostatics, and ARSST. Christi Luks (Missouri University of Science and Technology) has her students role-play a hazardous chemical release in which the students respond as if it is an industrial accident. Students in the command center use walkie talkies to communicate with the simulated hazmat crew on site.

Some other resources for teaching process safety were mentioned:

- Jerry Forrest at Louisiana State University hosts quarterly process safety education meetings.
- Explore runaway reactions with simulations in Python, Matlab™, Polymath™, and Wolfram CDF Player™ from Fogler's textbook website [13] or SAFEChE [14].
- Risk Analysis Screening Tool (RAST) and Chemical Hazard Engineering Fundamentals (CHEF) Calculation Aid are software programs available from the Center for Chemical Process Safety [15]. These support hazards identification and risk assessment, incident scenarios, hazards and operability studies, and layers of protection analysis.

Summary

In this proceedings paper, we have reanalyzed survey data to show that more institutions that require SAChE modules expect higher comprehension levels of process safety and management of risk outcomes than institutions that do not require any modules. We have provided advice for teaching process safety that was collected during the panel discussion at the AIChE Annual Meeting. We have listed some additional resources for teaching process safety. We hope that the information here is useful for process safety instructors and chemical engineering departments.

References

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