INCORPORATING CHEMICAL PROCESS SAFETY EDUCATION INTO A CHEMICAL ENGINEERING CURRICULUM USING THE FOUR CATEGORIES OF CHANGE STRATEGIES MODEL

A Dissertation Presented

By

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Table of Contents

Acknowledgements ........................................................................................................... i
Table of Contents .............................................................................................................. ii
List of Tables ................................................................................................................ v
List of Figures .................................................................................................................. vi
1 Introduction .................................................................................................................. 1
2 Literature Review ......................................................................................................... 3
  2.1 Chemical Process Safety Concepts and Resources .................................................. 12
  2.2 Proposed Change Model for Integration of Chemical Process Safety into the
      Curriculum ................................................................................................................ 22
      2.2.1 Creating a Vision ............................................................................................. 26
      2.2.2 Developing and Enacting Policy: ABET and Course Outcomes ..................... 27
      2.2.3 Developing Curriculum: The Connection Between the Core Curriculum and
          Process Safety Outcomes .................................................................................. 35
      2.2.4 Reflection on Chemical Process Safety Integration ....................................... 40
3 Specific Aims of this Dissertation .................................................................................. 42
  3.1 Aim 1: Creating a Shared Vision ........................................................................... 43
  3.2 Aim 2: Enacting Policy ......................................................................................... 43
  3.3 Aim 3: Creating and Disseminating Curriculum .................................................... 44
  3.4 Aim 4: Reflecting on Change ................................................................................ 44
4 Methods: ....................................................................................................................... 45
  4.1 Vision ....................................................................................................................... 46
  4.2 Policy ....................................................................................................................... 51
  4.3 Curriculum ............................................................................................................... 51
  4.4 Reflective Teachers ............................................................................................... 52
5 Results and Discussion ................................................................................................. 54
  5.1 Vision ....................................................................................................................... 54
  5.2 Policy ....................................................................................................................... 59
  5.3 Curriculum ............................................................................................................... 64
  5.4 Reflective Teachers ............................................................................................... 70
  5.5 Continuous Improvement Process Specifications .................................................. 84
  5.6 Intellectual Property .............................................................................................. 85
  5.7 Sustainability .......................................................................................................... 86
  5.8 Economics .............................................................................................................. 87
6 Conclusions .................................................................................................................... 88
7 Future Work .................................................................................................................. 90
8 References .................................................................................................................... 92
9 Appendices ................................................................................................................... 96
  9.1 Definitions ............................................................................................................... 96
  9.2 Chemical Process Safety Survey .......................................................................... 98
  9.3 Example of Pre-and Post-Course Outcome Survey .............................................. 104
  9.4 Sample Course iAssess Document ...................................................................... 106
  9.5 Safety Needs Assessment ...................................................................................... 115
  9.6 Course iAssess Forms ........................................................................................... 118
    9.6.1 CHME 2308 Conservation Principles ............................................................ 118
9.6.2 CHME 2311 Transport Lab 1 ................................................................. 122
9.6.3 CHME 3000 Professional Issues in Engineering ................................ 128
9.6.4 CHME 3312 Transport 2 ................................................................. 131
9.6.5 CHME 4510 Kinetics ................................................................. 133
9.6.6 CHME 4512 Process Control ....................................................... 135
9.6.7 CHME 4701 Capstone 1 ................................................................. 137
9.6.8 CHME 4703 Capstone 2 ................................................................. 139
9.7 Digication e-Portfolio Instructions and Template .................................. 141
9.8 Course Materials ........................................................................... 143
  9.8.1 Conservation Principles ............................................................... 144
  9.8.2 Lab 1 ......................................................................................... 144
  9.8.3 Professional Issues ................................................................. 152
  9.8.4 Transport 2 ............................................................................. 154
  9.8.5 Kinetics ................................................................................. 154
  9.8.6 Process Control ....................................................................... 156
  9.8.7 Capstone 1 ............................................................................. 157
  9.8.8 Capstone 2 ............................................................................. 159
9.9 2018 ASEE Conference Presentation .................................................. 161
9.10 ABET Departmental Work Process SOP Developed in June 2018 ....... 163
List of Tables

Table 1: Top 50 Universities Graduating Chemical Engineering Students and Safety Course Offerings (2015-16) \(^{19}\) ...........................................................................................................8
Table 2: Colleges and Universities that Offer Chemical Process Safety Courses \(^{20}\) ....12
Table 3: Reference Material for Chemical Process Safety Curriculum Development ...20
Table 4: Program Assessment Methods \(^{41}\) .................................................................30
Table 5: Domains of Learning \(^{44} \, 45\) .............................................................................32
Table 6: The Six Cognitive Levels, Terms, and Assessment Tasks \(^{47}\) .........................33
Table 7: Summary of Course Categories and their Corresponding Credit Statistics \(^{48}\).36
Table 8: Chemical Engineering Faculty, Fall 2017 and Spring 2018 Courses, and Expertise .................................................................................................................................48
Table 9: Fall 2017 Faculty Schedules .............................................................................48
Table 10: Spring 2018 Faculty Schedules .....................................................................49
Table 11: Needs Assessment .........................................................................................55
Table 12: Chemical Process Safety Course Learning Outcomes Related to ABET and SChE Outcomes ......................................................................................................................61
Table 13: SChE Outcome Cognitive Learning Levels ....................................................62
Table 14: Course Outcomes for Chemical Process Safety and The Blooms Taxonomy Cognitive Level ..........................................................................................................................63
Table 15: Course Assessment Summary ......................................................................78
Table 16: Survey Response Numbers ...........................................................................81
Table 17: Number of Students Taking One or More Chemical Engineering Courses ...81
List of Figures

Figure 1: Impact of Design Choices on Cost .......................... 5
Figure 2: Northeastern University Chemical Engineering Process Safety Concept Map from the Course Learning Outcomes .................................... 15
Figure 3: Aspects of Systems to be Change to Create Sustainable Systemic Change ................................................................. 22
Figure 4: Categories to Barriers and Drivers for STEM Education Reform Identified by Faculty ....................................................... 25
Figure 5: Summary of Aims .......................................................... 45
Figure 6: Sample Northeastern University Chemical Engineering Curriculum (up to the class of 2021 Five Years, Three Co-ops in Spring/Summer ........ 50
Figure 7: Organization of Team ....................................................... 58
Figure 8: Map of Potential Connections Between ABET Outcomes (yellow and green boxes, green is explicitly safety related and yellow are not explicitly safety related) to SACHE Chemical Process Safety Outcomes (white) .......... 60
Figure 9: The Connections Between Course Outcomes 1-8 (white), Core Courses with No Outcomes (orange), Core Courses with One Outcome (yellow), Core Courses with 2+ Outcomes (green). ................................ 64
Figure 10: Courses with Integrated Chemical Process Safety .......................... 65
Figure 11: Course Grades for Implementation of All SACHE Outcomes on a Scale from 1-4. .............................................................. 70
Figure 12: Student Perception Change of the Course Outcome from the Beginning of the Semester to the End (Change Measured in Percent, All Values Increased) .......................................................... 71
Figure 13: Student Perspective of Courses where Chemical Process Safety Knowledge was Gained .................................................. 83
Figure 14: Chemical Engineering Curriculum Continuous Improvement Process .................................................................................. 89
1 Introduction

Process safety education and training at US colleges and universities is currently insufficient to meet industry needs. Failure to prepare students with essential process safety training can and does lead to catastrophic and financially devastating events. This is evident by a 2007 an explosion at T2 Industries in St. Petersburgh, Florida which caused damage across a quarter mile radius, injured 32 and killed four people, including the owner who was educated as a chemical engineer. The U. S. Chemical Safety Board (CSB) investigation report cited one of the root causes of the explosion as being a lack of understanding of the hazards associated with chemical processing which was a result of the lack of chemical process safety content in the undergraduate curriculum.

As a result of this incident, the U. S. Chemical Safety Board (CSB) sent specific recommendations to the Accreditation Board of Engineering and Technology (ABET) and ABET added process safety requirements to the chemical engineering program criteria which are necessary for a university to maintain accreditation. According to the requirements, universities must "provide a thorough grounding in the basic sciences including chemistry, physics, and/or biology…. The curriculum must include the engineering application of these basic sciences to the design, analysis, and control of chemical, physical, and/or biological processes, including the hazards associated with these processes."
The challenge to chemical engineering programs has been that the curriculum is already perceived as full by the faculty, so that adding more concepts is highly constrained. In addition, there are challenges associated with changing undergraduate instructional practices, especially if the educators themselves do not have the experience and/or background necessary for implementation. Chemical process safety is not a topic that was covered when all the professors were students.

To address the current needs of industry and society, higher education needs a systematic approach for creating sustainable curriculum changes. Historically, curriculums have been modified by changing course professors, changing text books, or adding courses to the curriculum. The challenge with the engineering curriculum is that it is already highly constrained and it doesn’t offer students much flexibility in customizing the curriculum, so adding another required course to the curriculum isn’t an option. Adding content to textbooks is an option, however not easily implementable given the wide array of textbooks, number of authors, and timing of new additions. A new instructor is also an option; however, one instructor will not create the necessary systemic change.

Therefore, the aim of this dissertation research will be to determine a method for creating measurable and sustainable integrated curriculum changes specifically applied to chemical process safety.
2 Literature Review

Catastrophic chemical process events have been happening since mass chemical production processes began. Notable incidents include: the release of methyl isocyanate in Bhopal, India in 1984 where over 2,000 people were killed; and more recently the release of millions of gallons of oil in the Gulf of Mexico, causing the largest environmental disaster in US history and costing at least $61 billion in damages. Another incident at T2 Laboratories on December 17, 2007, killed four people and damaging local businesses up to 1,700 feet away. A Chemical Safety Board investigation found that the chemical engineer and lead chemist went from a beaker to a 9,300-liter reactor without any formal hazard analysis in between. The Chemical Safety Board (CSB) concluded that the root cause was the lack of educational preparation that the chemical engineering and chemist had. They had not had any introduction into the hazards associated with exothermic batch reactions nor methods of hazards analysis during the design and production steps.

This explosion was caused by a runaway reaction in a system that was not effectively designed. This specific event lead to the 2011 incorporation of chemical process safety into the Accreditation Board for Engineering and Technology (ABET) accreditation requirements for all baccalaureate chemical engineering education programs. 7, 9

The challenge to undergraduate chemical engineering programs has been to adapt to industry needs, given a curriculum that is already perceived as full. Further barriers include the fact that the educators themselves do not always have
the experience and background necessary for implementation\textsuperscript{10} and the university tenure and merit review system rewards grantsmanship and scholarship \textsuperscript{11} over educational reform. So, integrating “the hazards associated” into a course or multiple courses, is not easy and it is not going to earn individuals’ tenure. However, it must be addressed for a university to maintain its accreditation status as well as for the benefit of industry and society.

Adding chemical process safety to the curriculum will also allow Northeastern graduates to stay competitive with other chemical engineering graduates. Industry is willing to pay significantly for chemical engineering expertise, according to National Association of Colleges and Employers (NACE), Glassdoor, PayScale and Salary.com, the current average starting salary for an entry level chemical engineer is between $68,000-$78,000.\textsuperscript{12,13,14,15} Other less financially competitive employers of graduating students include government agencies and graduate programs. All of these entities require their employees to have knowledge and skills in chemical process safety. Greater employee knowledge will add overall value to the program, agency or company which will be reflected in more cost effective and safer operations.

The development of a process which will impart this knowledge and skills to students is especially important for plant or process designers. Being aware of incident case studies which identify the causes and effects, as well as the technical challenges with designing a system, will enable graduates to be better designers. Students with this awareness, who employ inherently safer designs, as well as control and mitigation systems, will design a more robust system from the start.
Better designs lead to an overall cost savings, and save money over the lifetime of the project (Figure 1).

![Cost vs. Flexibility Diagram](image)

**Figure 1: Impact of Design Choices on Cost**

In day to day industrial operations, educating undergraduate students in chemical process safety will have positive financial impacts. Alcoa CEO, Paul O’Neil, said that, “effective management of worker safety and health protection is a decisive factor in reducing the extent and severity of work-related injuries and illnesses and their related costs. An effective safety and health management system forms the basis of good worker protection. It can save time and money. One estimate is that for every dollar spent, about $4 is recovered via increase productivity and efficiency.”

Implementing a process for continuous curriculum improvement will allow Northeastern to stay competitive as a Chemical Engineering Program. Currently Northeastern University’s Undergraduate Chemical Engineering program is ranked 49th by US News and World Reports. In terms of universities graduating students with chemical engineering degrees, the data from 2015-2016
demonstrates that there was a total of 48,139 students enrolled in undergraduate chemical engineering programs (Table 1).\textsuperscript{19} There were 9,864 total undergraduate degrees awarded in chemical engineering, of those 0.9% or 89 degrees were awarded by Northeastern University. The University of California, San Diego graduates the most with 1.96% or 193. Of the 152 reported programs, 31% graduate between 75 and 200 students and Northeastern is number 36 of the top 50 universities who graduate large numbers of chemical engineering students.

Direct competitors include other colleges and universities that have chemical engineering programs that include chemical process safety programs. Northeastern University graduates compete with these graduates for jobs. Other universities that offer specific courses in the area of chemical safety are listed in Table 2.\textsuperscript{20} It is important to note that the program requirements are important. Not all of these courses that are offered are required for the programs, nor are they offered to undergraduates. For example, Northeastern University offers a chemical process safety course; however, it is not a graduation requirement. Chemical engineering programs that incorporate safety into the curriculum are required to report it to ABET via its self-assessment review; however, there are no other required reporting.

The market for Northeastern graduates will continue to grow as a result of this dissertation because these graduates will meet a mandatory industrial need for knowledge and skills in process safety, through the present academic process. By creating an integrated education process that increases the chemical process safety knowledge and skills of the graduates, the Northeastern University chemical
engineering program will become a leader in chemical engineering education. The creation of an adaptable curriculum will enable the department to meet any future needs of society and industry.
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<th>Top 12 US News and World Report Rank</th>
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Table 1: Top 50 Universities Graduating Chemical Engineering Students and Safety Course Offerings (2015-16)
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<td>Princeton University</td>
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<td>1</td>
<td>Massachusetts Institute of Technology</td>
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<tr>
<td>8</td>
<td>California Institute of Technology</td>
<td></td>
<td>14</td>
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</tr>
</tbody>
</table>
2.1 Chemical Process Safety Concepts and Resources

Chemical process safety is a broad topic and it is often confused with lab safety, so it must be carefully defined. In a recent AIChE exchange post members were asked to describe chemical process safety; the responses included:

- "Process Safety addresses the control and prevention of fires, explosions, and accidental uncontrolled releases of hazardous substances."

- “Process Safety is a blend of engineering and management skills focused on preventing catastrophic accidents and near hits, particularly, structural collapse, explosions, fires and damaging releases associated with a loss of containment of energy or dangerous substances such as chemicals and petroleum products."

- “Process Safety is a complicated field and hard to explain to people you meet (and of course, you need to make it sound interesting!), so I always
ask Safety Professionals what they tell people when they are asked what they do. I’ve heard things from “I ensure the safety of our workers and the public” all the way to “I try to keep my company out of the newspaper.”

Kendall Werts, PE, Process Safety Engineer, Linde Gas, Tulsa OK

Or simply: “Keep it in the pipes.”

To add further specificity, in 2010 the Safety and Chemical Engineering Education (SACHe) committee (associated with the Center for Chemical Process Safety and American Institute of Chemical Engineers) surveyed faculty and industrial leaders to determine what is necessary for students to be able to do by the time they graduate in terms of chemical process safety. Based on the results of that survey, the following eight specific chemical process safety learning outcomes, that meet ABET criteria, were proposed.3

1. The graduate must understand the importance of process safety and the resources and commitment required. This should include the important incidents that define process safety, and how these incidents affected the practice of chemical engineering.
2. The graduate should be familiar with the major regulations that impact the safety of chemical plants.
3. The graduate must be able to characterize the hazards associated with chemicals and other agents. This must include toxic, flammable, and reactive hazards.
4. The graduate should understand the consequences of chemical plant incidents due to acute and chronic chemical releases and exposures.
5. The graduate must understand and be able to apply concepts of inherently safer design.

6. The graduate must understand how to control and mitigate hazards to prevent accidents. This should include generally accepted management systems, plant procedures and designs to prevent accidents.

7. The graduate should be reasonably proficient with at least one hazard identification procedure.

8. The graduate should have an introduction to the process of hazard evaluation and risk assessment."

Even these learning outcomes are broad so specific concepts need to be identified in order to disseminate it to students. In order to do this, AIChE and CCPS have developed workshops and on-line modules for faculty and students to help them understand chemical process safety concepts. For faculty, there is a workshop that lasts several days, located at a chemical manufacturing facility. These workshops are offered during January and summer breaks and are free for faculty attendees (except the price of travel to and from the workshop). These workshops cover many of the SACHE learning outcomes and are taught by faculty and industry leaders in chemical process safety. It includes a tour of the manufacturing facility and discussions on the challenges the companies face with chemical process safety. Teaching materials developed by the faculty leaders are shared with the attendees. AIChE/CCPS also offers a one day workshop at the AIChE Annual Meeting. This workshop is also taught by industry and faculty leaders, covering much of the same material, in an abbreviated session.
For students, AIChE/CCPS offers a chemical process safety boot camp. This is taught by industry and faculty leaders on-site at the sponsoring university’s campus in one weekend. They cover the SACHE outcomes at a cost of approximately $1,000 per student. In addition, AIChE/CCPS also offers on-line certifications in the area of chemical process safety through AIChE Academy. More specifically targeted to students is the SACHE certificate courses, which are free to undergraduate students. This material takes about 15 hours to complete and gives a general understanding of the fundamentals of chemical process safety.

In 1990, CCPS published a book called Safety, Health, and Loss Prevention in Chemical Processes: Problems for Undergraduate Engineering Curricula. This book includes close to 100 different word problems related to chemical process safety mapped to the core chemical engineering courses. Figure 2 shows the concepts in this book mapped to the Northeastern University core curriculum.

Figure 2: Northeastern University Chemical Engineering Process Safety Concept Map from the Course Learning Outcomes
More specific resources are also available for each learning outcome. The Dow Lab Safety Modules discuss the characteristics of a sustainable safety culture which is relevant for developing an understanding of the importance of process safety and the resources and commitment required. Other sources which are relevant to this outcome include the the US. Chemical Safety Board, which reviews significant incidents that occur and identifies the causes. The AIChE, CCPS Process Safety Beacon is also a good source of information. This is a monthly e-mail that discusses significant and patterns of incidents.

Specific significant safety incidents are discussed in an “Introduction to Process Safety for Undergraduates and Engineers: and include: Flixborough (1974), Bhopal, India in 1984, and T2 Laboratories in 2007. These incidents cost the companies, communities and the environment billions of dollars and many lives were lost. The underlying causes of these incidents ranged from a lack of company safety culture and effective management systems, to inappropriate system design and a lack of sufficient hazard and risk analysis.

In order for students to demonstrate an awareness of chemical process safety standards and regulations, they need to be knowledgeable about agencies such as the Occupation and Safety and Health Association (OSHA) and their Process Safety Management (PSM) standards which specify safe operating practices. They also need knowledge of the Environmental Protection Agency’s (EPA) Risk Management Plan(RMP) which requires industries that work with highly hazardous chemicals to have a plan to minimize risk.
Other agencies that have relevant safety information include The National Fire Protection Association (NFPA), National Institute for Occupational Safety and Health (NIOSH), and the association advancing occupational and environmental health (ACGIH). With an increasingly global society, an awareness of international regulations is also important. International regulations include: Seveso (Europe), 26 The Factories Act (India), 27 NORMA Official Mexicana (Mexico), 28 and the Health and Safety Executive: Control of Major Accident Hazards (COMAH)(United Kingdom). 29

The Safety Data Sheet (SDS) is the first-place students should turn to for information regarding the hazards associated with chemicals. This document contains 16 sections outlining the safe use of a chemical. The SDS identifies hazards such as toxicity, flammability and corrosiveness as well as other health hazards. They also specify the exposure and flammability limits of the chemical. Resources such as CAMEO, supported by the EPA, or CRW, supported by CCPS, are useful for identifying reactive chemicals.

Knowing the consequences of releases and exposures includes understanding flammability limits, exposure limits and toxic effects, also described in the SDS. The use of source models and release models (such as the EPA’s ALOHA program) quantify the rate and spread of the release. The textbook “Chemical Process Safety, Fundamentals with Applications” has extensive information and examples on source and release models. Case studies are useful for demonstrating the consequences of these releases on the health and the environment.

Designing, controlling and mitigating hazards in a process is extremely important for chemical engineers. Applying methods of inherently safer design means incorporating
methods such as minimizing, substituting, moderating and simplifying in the design process. Minimizing means using less chemicals or storing less materials. Substitution means using less hazardous materials, chemistry and/or processes. Moderation of conditions, for example means operating at lower temperature and pressures. Simplifying the process takes into consideration the operators and keeps the process simplified to reduce the chance of mistakes. Overall, an inherently safer design means accounting for the intrinsic, physical and chemical properties in a process and making it safer in the design stage.

Even if a design is inherently safer, there may still be hazards that require control and mitigation. The control and mitigation of hazards means that designs need to incorporate passive, active and procedural methods into the process. Passive methods include reducing or eliminating the hazard including the frequency or consequence without relying on an actively functioning device. Active methods include using a device or control systems. Control systems with redundancy improve reliability and minimizes human interactions which can reduce failures due to human error. Procedural methods include management and procedures, safety rules, standards, counter measures, and emergency response and training. Designs should include layers of protection so that it takes more than one degree of failure to cause an incident. A basic understanding of inherently safer design, control and mitigation methods are covered in the SACHe certificate program.

Procedures for hazard analysis include qualitative methods such as checklists, Failure Mode and Effect Analysis (FMEA), Bow Tie Analysis, Hazard and Operability (HAZOP) analysis, and What-if. Quantitative analysis includes Event Tree, Fault Tree and
Layers of Protection Analysis (LOPA). Using these methods will determine the hazards and consequences of an event happening.

Utilizing the information from the hazard analysis, a risk assessment can be done. The risk assessment takes into account the hazard, the probability of an event will occur as well as the frequency of that event. In other words, what can go wrong; how bad can it be; and how often can it happen? This information helps with design and also the cost estimate of a process which quantifies the need for a specific design choice. Identifying hazards and managing risks is also discussed in The Dow Lab Safety Modules under Plan, Evaluate, and Execute. Recommendations for references for all the outcomes are listed in Table 3.
## Table 3: Reference Material for Chemical Process Safety Curriculum Development

<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
<th>Source Type</th>
<th>SACHES Outcome</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIChE Center for Chemical Process Safety (CCPS)</td>
<td>Introduction to Process Safety for Undergraduates and Engineers (2016)</td>
<td>Book</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AIChE Center for Chemical Process Safety (CCPS)</td>
<td>Faculty Workshops: On-Site</td>
<td>Workshop</td>
<td>1-8</td>
<td><a href="https://www.aiche.org/ccps/resources/conferences/events/faculty-workshops">https://www.aiche.org/ccps/resources/conferences/events/faculty-workshops</a></td>
</tr>
<tr>
<td>AIChE Center for Chemical Process Safety (CCPS)</td>
<td>Student Boot Camps</td>
<td>Workshop</td>
<td>1-8</td>
<td><a href="https://www.aiche.org/ccps/resources/conferences/events/student-bootcamps">https://www.aiche.org/ccps/resources/conferences/events/student-bootcamps</a></td>
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<tr>
<td>Author</td>
<td>Title</td>
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<td>Link</td>
</tr>
<tr>
<td>--------</td>
<td>-------</td>
<td>-------------</td>
<td>---------------</td>
<td>------</td>
</tr>
<tr>
<td>Safety and Chemical Engineering Education (SAChE)</td>
<td>Materials for Faculty</td>
<td>On-Line</td>
<td>1-8</td>
<td><a href="http://sache.org/products_by_course.asp">http://sache.org/products_by_course.asp</a></td>
</tr>
<tr>
<td>American Institute for Chemical Engineers (AIChE)</td>
<td>AIChE Academy Education</td>
<td>On-Line</td>
<td>1-8</td>
<td><a href="https://www.aiche.org/academy">https://www.aiche.org/academy</a></td>
</tr>
<tr>
<td>U.S. Chemical Safety Board (CSB)</td>
<td>CSB Investigations</td>
<td>On-Line</td>
<td>1</td>
<td><a href="http://www.csb.gov/">http://www.csb.gov/</a></td>
</tr>
<tr>
<td>Chemical Safety Software</td>
<td>Safety Data Sheet Search</td>
<td>On-Line</td>
<td>3</td>
<td><a href="https://chemicalsafety.com/sds-search/">https://chemicalsafety.com/sds-search/</a></td>
</tr>
</tbody>
</table>
2.2 Proposed Change Model for Integration of Chemical Process Safety into the Curriculum

There has been a significant gap in what students learn in the university and what they need when working in industry, chemical process safety education is one area in need of change in higher education. There have been many studies researching how to overcome the gaps in education. Change in higher education is a relatively new research area and it has been noted that there are no theories yet, however, in a recent journal article, Henderson et al. have suggested one model for facilitating change in the undergraduate curriculum (Figure 3)\(^5\) This model draws on diffusion of innovations, complexity leadership, and social network theories.\(^{30, 31}\)

<table>
<thead>
<tr>
<th>Disseminating Curriculum &amp; Pedagogy</th>
<th>Developing Reflective Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Change Agent Role: Tell/Teach individuals about new teaching conceptions and/or practices and encourage their use</td>
<td>• Change Agent Role: Encourage/Support individuals to develop new teaching conceptions and/or practices</td>
</tr>
<tr>
<td>• Diffusion</td>
<td>• Scholarly Teaching</td>
</tr>
<tr>
<td>• Implementation</td>
<td>• Faculty Learning Communities</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Enacting Policy</th>
<th>Developing Shared Vision</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Change Agent Role: Enact new environmental features that require/encourage new teaching conceptions and/or practices</td>
<td>• Change Agent Role: Empower/Support stakeholders to collectively develop new environmental features that encourage new teaching conceptions and/or practices</td>
</tr>
<tr>
<td>• Quality assurance</td>
<td>• Learning organizations</td>
</tr>
<tr>
<td>• Organizational Development</td>
<td>• Complexity leadership</td>
</tr>
</tbody>
</table>

Figure 3: Aspects of Systems to be Change to Create Sustainable Systemic Change\(^{31}\)

Henderson et al. claim that in order to change a system in higher education, at least one of the four change strategies need to be employed. The model describes how the change strategies span two continuums. One continuum is the aspects of a system
that need changing, which range from the environment and structures to individuals in the system. The other continuum is how well the intended outcome is defined. Whether the outcome is specifically prescribed (stated) to emergent, meaning that the outcome will be discovered along the way.

The literature reviewed identified four general strategies that facilitated change in higher education. They also identified the importance of a “Change Agent” in facilitating these changes. A change agent is an individual or group attempting to change the practices of instructors.

One strategy is “Disseminating Curriculum and Pedagogy”. This strategy focuses on changing the system through the individual instructor using prescribed outcomes. The role of the change agent is to use their expert knowledge to motivate and share knowledge with instructors to change the curriculum or pedagogy. Common methods to implement this strategy include discussions and workshops.  

“Developing Reflective Teachers” is another individual strategy, but this focuses on emerging outcomes. This means that through reflection of teaching practices, new outcomes may be discovered. The role of the change agent in this strategy is to provide instructors with activities to promote reflection. Methods used to develop reflective teachers include discussions amongst learning communities and reflective writing practices.  

“Enacting Policy” is aimed at changing the environment or structures through prescribed outcomes. Enacting policy entails developing environments such as rules, reward systems, reporting requirements or support structures to encourage instructors to change their practices. The change agent uses specialized knowledge to develop new
environments which encourage and enable instructors to change their practices. Methods include identifying incentives to motivate change.  

The final change strategy identified is “Developing Shared Vision”. Developing a shared vision develops an emergent outcome for the environment. The change agent encourages the faculty to work together towards a common goal or vision for the department. One method used for developing a shared vision is to use the change agent as a consultant to identify needs and implement a strategy to meet those needs.  

In the literature review, Henderson, et. al. discovered two key practices in the Disseminating and Enacting Policy change strategies that do not work. For Disseminating change strategies, creating and disseminating curricular content is not effective. Workshops are also not effective unless they last longer than 4 weeks or there are a series of workshops that are significantly related. Enacting Policy change strategies are not effective if the policies are top down or uniform such that they don’t encourage individualized solutions.  

Several best practices were identified in all categories except Shared Vision. Best practices in terms of Disseminating strategies include coordinated and focused efforts, efforts that last longer than a semester, the instructor receives performance evaluation and feedback, and deliberate attention to changing faculty conceptions. Successful Policy strategies are typically locally developed within a small entity such as a department. Developing Reflective Teachers often involves collaborative communities and consultants which give targeted feedback to instructors and encourage reflection. Henderson, et. al. report that there is no significant literature describing the best practices in developing Shared Vision. Overall, more effective change was noted when
more than one change strategy was employed, however this practice is rare because different learning communities employ different strategies and each learning community rarely take a holistic look at the system.

When choosing change strategies it is important to identify variables that impact change. Noted variables in higher education include disciplinary affiliation, loose coupling, and reward structure. Shadle et al. researched specific barriers and drivers for educational based instructional practice which promote systemic change in STEM education and they found the most significant barrier is time constraints (Figure 4).  

![Figure 4: Categories to Barriers and Drivers for STEM Education Reform Identified by Faculty.](image-url)
It is also important to identify drivers to change because leveraging the drivers seem to be the key to overcoming the barriers. Shandle et al. also identified drivers for change. They included providing flexibility and encouraging exploration, aligning with existing resources, improving teaching and assessment, encouraging collaboration, and expanding on current practices (Figure 4).  

Higher education is not the only area where system change has been difficult. Creating a process safety culture in industry has also been a challenge and extensive work has been done to identify methods for creating change. The first step that has been identified is that the program’s process safety culture should be evaluated, since culture has been identified as a critical component of a successful chemical process safety program. This is similar to creating a shared vision as identified in the Henderson model. The second step is to identify approaches and content that promote the mission of the company. This is similar to identifying the Policy, Curriculum and Pedagogy necessary for safety implementation in the department. The final step is to implement the approach, and measure to see if the mission was met, which aligns with creating Reflective Teachers.

2.2.1 Creating a Vision

Creating a vision requires a change agent that will motivate the faculty to work together towards a common goal or vision for the department. There is a need in chemical engineering programs to integrate chemical process safety into the curriculum to meet ABET accreditation requirements. The role of the change agent in this case is to help the faculty recognize the need and help articulate the vision.
2.2.2 Developing and Enacting Policy: ABET and Course Outcomes

Enacting policy entails developing environments such as rules, reward systems, reporting requirements or support structures to encourage instructors to change their practices. Before any policy should be developed, there should be an understanding of the current policies. Current policies include ABET requirements at the global level, down to instructor specified policies which are outlined in course syllabi.

2.2.2.1 ABET Policy

In terms of accredited engineering programs, ABET criteria must be met. The specific ABET requirements for Chemical Engineering Program accreditation are described in General Criteria 3 and 5 as well as the Specific Program Criteria. Note in General Criterion 3, student outcomes c, f, h and i and the Specific Program Criteria relate to chemical process safety education.

General Criterion 3 is described below:

"The program must have documented student outcomes that prepare graduates to attain the program educational objectives. Student outcomes are outcomes (a) through (k) plus any additional outcomes that may be articulated by the program.

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice."  

General Criterion 5 states:

“The curriculum requirements specify subject areas appropriate to engineering but do not prescribe specific courses. The faculty must ensure that the program curriculum devotes adequate attention and time to each component, consistent with the outcomes and objectives of the program and institution. The professional component must include:

(a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline. Basic sciences are defined as biological, chemical, and physical sciences.

(b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student’s field of study. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other. Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process
(often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.

(c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives.

Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.

One year is the lesser of 32 semester hours (or equivalent) or one-fourth of the total credits required for graduation." 9

The Specific Program Criterion states that:

“1. Curriculum

The curriculum must provide a thorough grounding in the basic sciences including chemistry, physics, and/or biology, with some content at an advanced level, as appropriate to the objectives of the program. The curriculum must include the engineering application of these basic sciences to the design, analysis, and control of chemical, physical, and/or biological processes, including the hazards associated with these processes.” 9

University programs may add additional outcomes to their specific program and all outcomes must be published on the website and in the curriculum guides. For ABET accreditation, programs must demonstrate progress towards meeting these outcomes.
In order to determine whether or not a program change has occurred, like incorporating chemical process safety across the curriculum, the program needs to be assessed. Assessment of learning at the program level includes using direct and indirect measurement methods. Indirect methods are where students describe their learning, whereas direct assessment methods are where students demonstrate their learning (Table 4). Written surveys and focus groups will be used to indirectly measure the change and e-portfolios and concept maps will be used as direct measurements to assess whether or not a significant program change has been implemented.

Table 4: Program Assessment Methods

<table>
<thead>
<tr>
<th>Indirect Assessment</th>
<th>Direct Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Written Surveys</td>
<td>Standardized Exams</td>
</tr>
<tr>
<td>Questionnaires</td>
<td>Portfolios</td>
</tr>
<tr>
<td>Exit Interviews</td>
<td>Simulations</td>
</tr>
<tr>
<td>Archival Records</td>
<td>Performance Appraisal</td>
</tr>
<tr>
<td>Focus Groups</td>
<td>External Examiner</td>
</tr>
<tr>
<td></td>
<td>Oral Exams</td>
</tr>
<tr>
<td></td>
<td>Concept maps</td>
</tr>
</tbody>
</table>

2.2.2.2 Course Policy
Policy at the course level is specified in the course syllabus. This document is generated by the faculty teaching the course and part of it outlines the course outcomes which specify what students will be able to demonstrate by the end of a course. It is recommended that course outcomes map to the ABET outcomes to simplify the accreditation process.
Faculty create the course outcomes, which describe the extent to which students need to learn the concept being taught. It is written as a statement describing what a student will be able to do by the end of a course. Several taxonomies have been developed for educators to articulate the level of learning one achieves in a learning outcome. This is typically the verb in the learning outcome. Bloom’s cognitive taxonomy is often referenced; however, there are several other learning taxonomies as well which include interpersonal, psychomotor, affective, and perceptual domains. There are eight taxonomies and five to six levels of learning in each. These taxonomies are described in Table 5 along with their level descriptors. An example of a process safety learning outcome might be: “The student will be able to remember the meaning of LD_{50}.”, the learning outcome is in the Knowledge domain: Cognitive, Factual, and lower order of: Remembering.

The learning outcome is important because this can help specify the most appropriate method for assessment. Depending on the learning outcome level, different assessments are recommended. Table 6 lists learning levels and appropriate assessment methods. Lower levels of learning utilize assessment tools, such as true/false questions, whereas higher levels of learning require assessment tools such as conducting independent research.
Table 5: Domains of Learning\textsuperscript{44, 45}

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Lower Order</th>
<th>Higher order</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive: Factual Knowledge</td>
<td>Knowledge of terminology</td>
<td></td>
</tr>
<tr>
<td>Cognitive: Conceptual Knowledge of classifications, models and theories</td>
<td>Remember</td>
<td>Apply</td>
</tr>
<tr>
<td>Cognitive: Procedural Knowledge of subject-specific skills, techniques and methods</td>
<td>Understand</td>
<td>Evaluate</td>
</tr>
<tr>
<td>Cognitive: Metacognitive Self and strategic knowledge</td>
<td>Apply</td>
<td>Evaluate</td>
</tr>
<tr>
<td>Interpersonal</td>
<td>Relating to and interacting with others</td>
<td>Supporting</td>
</tr>
<tr>
<td>Psychomotor</td>
<td>Physical skills</td>
<td>Move</td>
</tr>
<tr>
<td>Affective</td>
<td>Internalization of positive attitude</td>
<td>Pay Attention</td>
</tr>
<tr>
<td>Perceptual\textsuperscript{46}</td>
<td>Pattern recognition</td>
<td>Sensing</td>
</tr>
</tbody>
</table>
Table 6: The Six Cognitive Levels, Terms, and Assessment Tasks

<table>
<thead>
<tr>
<th>Cognitive Learning Level (from low to high)</th>
<th>Examples of Level Indicator Verbs Used in Learning Outcome</th>
<th>Examples of Assessment Tool for Each Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Knowledge:</td>
<td>Define</td>
<td>Multiple choice question</td>
</tr>
<tr>
<td>Remembering previously learned information</td>
<td>Describe</td>
<td>Fill in the blank question</td>
</tr>
<tr>
<td>Example:</td>
<td>Label</td>
<td>Oral response</td>
</tr>
<tr>
<td>Memory of specific facts, terminology,</td>
<td>Recite</td>
<td>True/false question</td>
</tr>
<tr>
<td>rules, sequences, procedures, classifications, categories, criteria, methodology, principles, theories and structure</td>
<td>Select</td>
<td>Develop a list</td>
</tr>
<tr>
<td></td>
<td>State</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Write</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Identify</td>
<td></td>
</tr>
<tr>
<td>2 Comprehension:</td>
<td>Match</td>
<td>Give an analogy</td>
</tr>
<tr>
<td>Grasping the meaning of information</td>
<td>Paraphrase</td>
<td>Create an outline</td>
</tr>
<tr>
<td>previously presented</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Example:</td>
<td>Restate</td>
<td>Summarize in your own words</td>
</tr>
<tr>
<td>Stating problem in own words, translating</td>
<td>Illustrate</td>
<td>Create a concept map</td>
</tr>
<tr>
<td>a chemical formula, understanding a flow</td>
<td>Compare</td>
<td>Draw a diagram</td>
</tr>
<tr>
<td>chart, translating words and phrases</td>
<td>Predict</td>
<td>Graph an answer</td>
</tr>
<tr>
<td>from a foreign language</td>
<td>Defend</td>
<td>Match a term with a definition</td>
</tr>
<tr>
<td></td>
<td>Explain</td>
<td></td>
</tr>
<tr>
<td>3 Application:</td>
<td>Apply</td>
<td>Compute an answer</td>
</tr>
<tr>
<td>Using principle/formula/processes</td>
<td>Change</td>
<td>Solve a problem similar to another problem</td>
</tr>
<tr>
<td>previously learned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Example:</td>
<td>Make</td>
<td>Solve a problem in a new setting</td>
</tr>
<tr>
<td>Taking principles learned in math and</td>
<td>Model</td>
<td>Create a model</td>
</tr>
<tr>
<td>applying them to figuring the volume of a</td>
<td>Show</td>
<td>Write an essay that requires</td>
</tr>
<tr>
<td>cylinder in an internal combustion engine</td>
<td>Calculate</td>
<td>the use of concepts learned</td>
</tr>
<tr>
<td></td>
<td>Examine</td>
<td>Use theory to explain an event or phenomena</td>
</tr>
<tr>
<td></td>
<td>Solve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use</td>
<td></td>
</tr>
<tr>
<td>Cognitive Learning Level (from low to high)</td>
<td>Examples of Level Indicator Verbs Used in Learning Outcome</td>
<td>Examples of Assessment Tool for Each Level</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-----------------------------------------------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td><strong>4 Analysis:</strong></td>
<td>Analyze, Compare/Contrast, Differentiate, Categorize, Distinguish, Relate</td>
<td>Deconstruct a model, Identify differences, Group like items together, Identify what is missing, Identify cause and effect, Discuss and event from multiple perspectives, Present the potential impact resulting from a decision or choice, Perform a Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis</td>
</tr>
<tr>
<td>Example:</td>
<td>Differentiate, Categorize, Distinguish, Relate, Differentiate, Discuss and event from multiple perspectives, Present the potential impact resulting from a decision or choice, Perform a Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis</td>
<td>Group like items together, Identify what is missing, Identify cause and effect, Discuss and event from multiple perspectives, Present the potential impact resulting from a decision or choice, Perform a Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis</td>
</tr>
<tr>
<td><strong>5 Evaluation:</strong></td>
<td>Evaluate, Select, Recommend, Rank, Critique, Judge, Assess</td>
<td>Choose best among options and defend choice, Rank from best to worst using established criteria, Develop criteria for judgement and apply to a solution, Recommend and defend choice for action, Present pros and cons of approach, Determine degree of success or failure of an action or event</td>
</tr>
<tr>
<td>Example:</td>
<td>Evaluate, Select, Recommend, Rank, Critique, Judge, Assess</td>
<td>Choose best among options and defend choice, Rank from best to worst using established criteria, Develop criteria for judgement and apply to a solution, Recommend and defend choice for action, Present pros and cons of approach, Determine degree of success or failure of an action or event</td>
</tr>
<tr>
<td><strong>6 Create:</strong></td>
<td>Make, Generate, Build, Form, Construct, Design, Fashion, Produce</td>
<td>Create a capstone project, Complete a summative class project, Write a summative paper in a course, Write a thesis, Write a dissertation, Design an original approach to a situation or problem, Conduct independent research</td>
</tr>
<tr>
<td>Example:</td>
<td>Make, Generate, Build, Form, Construct, Design, Fashion, Produce</td>
<td>Create a capstone project, Complete a summative class project, Write a summative paper in a course, Write a thesis, Write a dissertation, Design an original approach to a situation or problem, Conduct independent research</td>
</tr>
</tbody>
</table>
2.2.3 Developing Curriculum: The Connection Between the Core Curriculum and Process Safety Outcomes

In order to develop a curriculum, the current curriculum needs to be analyzed since the chemical engineering curriculum varies from university to university. In 2017, Voronov et al. analyzed the chemical engineering curricula of 148 different universities in the United States and they reported the frequency of courses topics for undergraduate chemical engineers. Of the courses reported by Voronov et al. eight courses seem to represent the “core of chemical engineering” and had a frequency of 97% or above: Chemical Process Calculations, Thermodynamics, Transport and Separations, Kinetics and Reactions, Process Control, Chemical Engineering Lab and Process Design (Table 7).

Furthermore in a 2017 ASEE conference paper, Vigeant et al. concluded after their analysis of the chemical engineering curriculum that “Taken as a whole, students from 1990 would find much that they recognize in the chemical engineering curricula of today, while they might not recognize the classroom activities or co-curricular opportunities as familiar.”
Table 7: Summary of Course Categories and their Corresponding Credit Statistics

<table>
<thead>
<tr>
<th>Category</th>
<th>Avg. w/o Zeros</th>
<th>Avg. w/o Zeros</th>
<th>Std. Dev. w/o Zeros</th>
<th>Std. Dev. w/o Zeros</th>
<th>%RSD w/o Zeros</th>
<th>Min w/o Zeros</th>
<th>Max w/o Zeros</th>
<th>Median w/o Zeros</th>
<th>%Freq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chem. Proc. Calc.</td>
<td>3.6</td>
<td>3.6</td>
<td>1.2</td>
<td>1.1</td>
<td>35</td>
<td>1</td>
<td>9</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Thermo I</td>
<td>3.3</td>
<td>3.3</td>
<td>0.9</td>
<td>0.5</td>
<td>28</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Thermo II</td>
<td>1.8</td>
<td>1.8</td>
<td>1.5</td>
<td>0.4</td>
<td>85</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Tbc. Thermo</td>
<td>4.8</td>
<td>4.8</td>
<td>1.4</td>
<td>1.4</td>
<td>30</td>
<td>2</td>
<td>8</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Fluid Flow</td>
<td>2.1</td>
<td>2.1</td>
<td>1.5</td>
<td>0.4</td>
<td>70</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Heat &amp; Mass Trans.</td>
<td>1.0</td>
<td>1.0</td>
<td>1.2</td>
<td>1.6</td>
<td>158</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Fluid &amp; Heat Trans.</td>
<td>0.4</td>
<td>0.4</td>
<td>1.1</td>
<td>0.4</td>
<td>264</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Heat/Trans.</td>
<td>1.2</td>
<td>1.2</td>
<td>1.4</td>
<td>0.4</td>
<td>140</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Mass Trans.</td>
<td>1.2</td>
<td>1.2</td>
<td>1.6</td>
<td>0.6</td>
<td>131</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Transp. Phen.</td>
<td>1.8</td>
<td>1.8</td>
<td>2.4</td>
<td>1.7</td>
<td>132</td>
<td>0</td>
<td>8</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Tbc. Transport</td>
<td>7.5</td>
<td>7.5</td>
<td>2.0</td>
<td>2.0</td>
<td>26</td>
<td>3</td>
<td>8</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Sepn. Proc.</td>
<td>2.3</td>
<td>2.3</td>
<td>1.6</td>
<td>0.7</td>
<td>72</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Transp + Sepn.</td>
<td>9.8</td>
<td>9.8</td>
<td>2.1</td>
<td>2.1</td>
<td>21</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>3</td>
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<tr>
<td>Kinetics &amp; React.</td>
<td>3.2</td>
<td>3.2</td>
<td>0.7</td>
<td>0.7</td>
<td>23</td>
<td>3</td>
<td>16</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Model/Number.</td>
<td>2.6</td>
<td>2.6</td>
<td>1.7</td>
<td>1.1</td>
<td>67</td>
<td>0</td>
<td>7</td>
<td>7</td>
<td>3</td>
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<tr>
<td>Control</td>
<td>3.1</td>
<td>3.1</td>
<td>0.8</td>
<td>0.7</td>
<td>25</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>ChE Lab I</td>
<td>2.5</td>
<td>2.5</td>
<td>1.2</td>
<td>1.2</td>
<td>48</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>ChE Lab II</td>
<td>2.6</td>
<td>2.6</td>
<td>1.4</td>
<td>1.4</td>
<td>68</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Total Labs</td>
<td>4.5</td>
<td>4.5</td>
<td>1.9</td>
<td>1.9</td>
<td>42</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Proc. Design</td>
<td>5.2</td>
<td>5.2</td>
<td>1.8</td>
<td>1.8</td>
<td>35</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Statics</td>
<td>0.5</td>
<td>0.5</td>
<td>2.8</td>
<td>1.1</td>
<td>222</td>
<td>0</td>
<td>3.7</td>
<td>3.7</td>
<td>0</td>
</tr>
<tr>
<td>Materials</td>
<td>1.5</td>
<td>1.5</td>
<td>3.1</td>
<td>1.6</td>
<td>105</td>
<td>0</td>
<td>8</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Proc. Safety</td>
<td>0.5</td>
<td>0.5</td>
<td>2.6</td>
<td>1.1</td>
<td>297</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Biology</td>
<td>1.1</td>
<td>1.1</td>
<td>3.5</td>
<td>1.7</td>
<td>158</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>BioXEng</td>
<td>0.8</td>
<td>0.8</td>
<td>3.1</td>
<td>1.4</td>
<td>169</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Total Bio.</td>
<td>1.9</td>
<td>1.9</td>
<td>3.8</td>
<td>2.2</td>
<td>116</td>
<td>0</td>
<td>9</td>
<td>9</td>
<td>0.5</td>
</tr>
<tr>
<td>Total Credits</td>
<td>129.6</td>
<td>129.6</td>
<td>3.6</td>
<td>3.6</td>
<td>114</td>
<td>1</td>
<td>138</td>
<td>138</td>
<td>130</td>
</tr>
</tbody>
</table>

%Freq. represents the percentage frequency of the credit statistics.
In Northeastern University’s Chemical Engineering Program there are 12 core courses, which teach these eight chemical engineering fundamentals. These courses are:

1. Sophomore level Conservation Principles (4 credits)
2. Sophomore/Middler level Laboratory 1 (2 credits)
3. Sophomore/Middler level Transport 1 (4 credits)
4. Sophomore/Middler level Thermodynamics 1 (4 credits)
5. Middler/Junior level Lab 2 (2 credits)
6. Middler/Junior level Transport 2 (4 credits)
7. Middler/Junior level Thermodynamics 2 (4 credits)
8. Middler/Junior level Professional Issues (4 credits)
9. Senior level Kinetics/Reactor Design (4 credits)
10. Senior level Process Control (4 credits)
11. Senior level Capstone 1 (4 credits)
12. Senior level Capstone 2 (4 credits)

Conservation Principles is the first course students take as a chemical engineer. The course presents an overview of chemical engineering and it focuses specifically on the fundamentals associated with material and energy balance calculations, meaning that mass and energy are conserved in a system.

As an introductory course, (Outcome 1) introducing major chemical incidents, such as Bhopal (1984), and how they have shaped the practice of chemical engineering would be appropriate. Other outcomes that match to specific content of the course include (Outcome 3) hazards associated with chemicals.
This can be identified for each chemical identified in a problem. Also (Outcome 4) toxic and flammable releases can be analyzed using mass balances. If there is a release into a room and there is an inlet and outlet flow, students can identify the concentration of flammable or toxic material in the space.

Transport 1 and 2 as well as the lab courses cover the fundamentals of momentum, mass, and heat transfer. These fundamentals connect with SAcHE outcomes (1, 3, 4, 7 and 8). Several incidents have been caused by momentum or heat imbalances. All problems analyzed in these courses include chemicals which could require an SDS review to identify the hazards associated with them. Releases involve momentum and mass transfer and conducting a hazard identification with or without a risk analysis could be an add-on to these problems to justify “why” these fundamentals are important. The lab can also address regulations, design, control and mitigation of hazards (Outcomes 2, 5 and 6) because these courses include a design component where students are designing an experiment which should include identifying regulations and standards as well as making sure the design is safe.

Thermodynamics 1 and 2 generally explore the First and Second Laws of Thermodynamics as well as more specifically, vapor-liquid equilibrium and expansion and compression of gasses. These fundamentals connect with (Outcome 1) safety incidents such as the vapor cloud explosion in Flixborough (1974). These courses may also address (Outcome 3) the consequences of releases including toxic and flammable exposures. Explosions can occur due to
constant pressure expansions, adiabatic expansions and isentropic expansion of a pressurized liquid.

Chemical Engineering students also take a Professional Issues course which addresses issues associated with professional development and working in industry. There are discussions on ethics and professional responsibilities which align with SACHE outcomes 1 & 2, identifying incidents and familiarity with regulations.

In Kinetics and Reactor Design, students understand the nature and mechanisms of different kinds of reaction, postulate reaction mechanisms from experimental data and choose and size reactors. The text book that is used for this course discusses the T2 incident (2007) which was caused by a runaway reaction. This incident maps directly to SACHE outcome 1. Hazards and the effects of releases (Outcomes 3&4) such as toxic effects on the human body can also be estimated from first order reactions. In addition, understanding inherently safer design (Outcome 5) and how to control and mitigate hazards (Outcome 6) can be determined by understanding the limiting steps in a reaction as well as the costs and benefits of using different types of reactors. Choices of different reactor designs also impacts potential hazards which could be identified by a method such as HAZOP or FMEA (Outcome 7).

In the Process Control course, students identify and design basic control systems using components and instrumentation system parameters, including sensors, transmitters, valves, and processes. Designing a process control system specifying component and instrumentation choices, so that the system is controlled
and mitigates hazards (Outcome 6) and conducting a layers of protection analysis on a process (Outcome 7) would also address two SACHE learning outcomes.

The Capstone 1 and 2 courses focus on the design and economics of chemical processes. Topics include computer simulation of steady-state processing conditions, selecting and sequencing process operations, integrating heat and power into the process, reactor design, preparing flow sheets and stream tables, and safety considerations in process design. These two courses are the culmination of the chemical engineering curriculum.

The outcomes in these courses could map to regulations (Outcome 2), which are necessary as part of design, understanding the hazards and consequences of a chemical release (Outcomes 3&4). All designs should consider safety as part of the design and strive for inherent safety (Outcome 5), or if that is not achievable, then control and mitigation (Outcome 6) systems must be implemented. The design should be analyzed for hazards (Outcome 7) and a risk assessment (Outcome 8) should be completed to help with the cost analysis, to determine how much is necessary as part of the design.

There are connections between the fundamentals of chemical process safety and every core chemical engineering course. The challenge is in implementation.

2.2.4 Reflection on Chemical Process Safety Integration

Implementing change for the sake of change is ineffective. Therefore, implementing reflective teaching practices is essential for promoting positive and effective curriculum changes.
Reflective teaching practices can include personal reflections as well as group reflections. Personal reflections can include thinking or writing which reflect on the goal, the outcome and whether or not the goal was met. Group reflections are similar, and the information is shared amongst the group working toward the common goal.

Methods of measurement that can be quantified to determine whether or not the education goal was met include faculty and student perception surveys and grades.

One useful qualitative method for determining whether or not an education goal was met is the generation of a work portfolio. This is also a reflective practice which students can derive benefit, because it teaches self-directed learning. E-Portfolios are electronic work portfolios. These portfolios are a repository for work generated in a program, and it helps students organize concepts. When a reflection is added, asking the student how the work generated contributes to the goal, it helps the students to see how concepts are interrelated.\textsuperscript{50}
3 Specific Aims of this Dissertation

The goal of this research is to design a change model and measure the impact for creating sustainable change in the chemical engineering curriculum by adding chemical process safety to the current curriculum.

**Mission Statement:** Integrate ABET mandated and SAcE recommended process safety learning outcomes into the curriculum beginning with the 2017-2018 academic year, and create a process for continuous curriculum improvement in the Chemical Engineering Department at Northeastern University, thus ensuring that Northeastern graduates students with the knowledge and skills necessary to meet the needs of society.

**Description**
Create a process for continuous curriculum improvement which enables undergraduate students to graduate with demonstrable knowledge and skills which are needed to meet the needs of industry and society. Specifically, they will be able to demonstrate knowledge and skills of chemical process safety (CPS) in eight key areas.

**Benefit Proposition**
- A process for continuous curriculum improvement in order to meet the current needs of industry and society
- Maintain ABET accreditation with a next general review (NGR) finding, meaning no deficiencies found.
- Accurate measurements that identify student knowledge and skills
- Increase faculty knowledge in current areas of need, including chemical process safety

**Key University Goals**
- Be a leader in chemical engineering education
- Improve university standings in the national rankings
- Maintain ABET accreditation
- Support industry’s need for process safety education in the undergraduate curriculum so that they have a fundamental knowledge of chemical process safety

**Primary Beneficiaries**
- Northeastern University (NU) Chemical Engineering Faculty and students

**Secondary Beneficiaries**
- Employers of NU’s Chemical Engineering graduates
- Graduate schools accepting NU’s Chemical Engineering graduates

**Assumptions**
- The process for continuous curriculum improvement and specifically implementing CPS will measurably improve teaching and assessment
- The process for continuous curriculum improvement and specifically implementing CPS will encourage collaboration and shared outcomes
Assumptions (cont.)

- The process for continuous curriculum improvement and specifically implementing CPS will expand on current practices
- The process for continuous curriculum improvement will show measurable student progress specifically in CPS concept development
- This process will enable the faculty to specifically develop competency in CPS
- The process will provide flexibility and encourage exploration specifically in CPS

Constraints

- All program improvements including the CPS curriculum, align with existing resources
- The process for implementing CPS doesn’t add more time constraints to students and faculty
- All changes must meet ABET requirements
- All SACHE safety outcomes must be incorporated across the curriculum
- Content can be integrated into the current chemical engineering courses by the faculty
- Content can be implemented for a cost less than $140,000
- Curriculum changes must be sustainable from academic year to academic year

Stakeholders

- Northeastern University’s (NU) Chemical Engineering students
- NU’s Chemical Engineering faculty
- Co-op companies affiliated with NU
- Employers of NU Chemical Engineering Graduates

3.1 Aim 1: Creating a Shared Vision

Reflect on the current state of chemical process safety and create a shared vision for what is should be. Develop a survey to identify the current chemical process safety needs, knowledge and skills of faculty, students and industry. Identify and create a team of faculty to work on creating a change in the curriculum.

3.2 Aim 2: Enacting Policy

Identify and specify the policy needed to meet ABET criteria and industry needs. Obtain the required approvals and post ABET student outcomes on the website and in department documentation maintain ABET accreditation. Write and
align the ABET student, SACHE and course outcomes. Post course outcomes in course syllabi.

3.3 Aim 3: Creating and Disseminating Curriculum

Design and specify the curriculum to be disseminated. Work with the team of faculty to clarify the course outcomes that meet chemical process safety and ABET criteria. Identify curriculum (content) and pedagogy (method of delivery) necessary to meet the course outcomes.

3.4 Aim 4: Reflecting on Change

Reflect on the change process used to create and disseminate the chemical process safety curriculum by analyzing course and survey measurements, individual faculty and group observations and discussions, and make future recommendations for course adjustments.
4 Methods:

The overall goal of this dissertation is to create and implement a process to introduce chemical process safety in the core undergraduate chemical engineering curriculum. It is also essential that the chemical process safety content meets ABET criteria and enables undergraduate students to “Hold paramount the safety, health and welfare of the public…” In order to do that, four change strategies were employed in order to increase the likelihood of sustainable and effective departmental change. The approach used the model for change suggested by Henderson et al to add chemical process safety to the current curriculum. Each strategy requires a change agent who was the Ph.D. candidate, Tracy Carter. Figure 5 is a summary of the Aims.

Note that this dissertation involves human subjects. Institutional Review Board (IRB) approval was not required because this work is considered quality improvement relative to changes in the curriculum.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Change Agent: Support faculty as we collectively develop chemical process safety concepts/practices</td>
<td>Change Agent: Support writing student outcomes and course outcomes that address ABET requirements</td>
<td>Change Agent: Share with faculty chemical process safety concepts and resources</td>
<td>Change Agent: Support faculty to reflect on practices using the IASSESS form and e-Portfolios</td>
</tr>
</tbody>
</table>

Figure 5: Summary of Aims
4.1 Vision

Creating a shared vision entails empowering stakeholders to collectively change the structure. It requires a change agent to identify the need for change and to initiate the discussion for change and to help form the vision for change. The change agent identified the chemical process safety education need and brought it to the attention of The Northeastern University Chemical Engineering Department Chairman, Vice Chairman and the Industrial Advisory Board (IAB). They agreed that there is a need for integrating chemical process safety across the curriculum in order to meet the needs of industry and to satisfy the ABET continuous improvement process requirements. Additional stakeholders needed for collaboration on chemical process safety education integration included faculty, students and industry.

In order to identify chemical process safety education needs, the following five-step method was utilized: 52

1. Gather Raw Data via Focus Groups: The groups identified were the Industrial Advisory Board, who also mentor the senior chemical engineering students, faculty, and leaders in chemical process safety. Surveys or interviews were conducted with these groups. The survey questions are located in Appendix 9.2.

2. Interpret the Raw Data: The results were interpreted and coded into needs statements.

3. Organize Needs into Hierarchy
   a. Redundant statements were eliminated
   b. Similar statements were grouped
c. Groups were labeled

d. Super or sub groups were created within categories

e. Needs were reviewed and edited as necessary

4. Establish Relative Importance of Needs: (5) Critical, (1) Undesirable

5. Reflect on the Results and Process

In order to create a process for continuous curriculum improvement in the area of chemical process safety, the specific faculty stakeholders needed to be identified. Critical faculty stakeholders include faculty who span the breath of the curriculum including course levels 2000, 3000, 4000, and 5000 (Figure 6 & Table 8).

Potential process barriers included time, and the potential drivers included providing flexibility and encouraging exploration, aligning with existing resources, improving teaching and assessment, encouraging collaboration and expanding on current practices. So, the first step was identifying stakeholders, expertise (Table 8), schedules (Table 9 & Table 10), and current core courses (Figure 6).

Once these faculty stakeholders were identified and survey responses were summarized, faculty meetings were held to discuss the outcomes of the survey. Next, discussions were held with each of the 19 faculty to identify goal alignment between the course and safety outcomes. Then one on one meetings were held between the candidate (Tracy Carter), as the change agent, and each faculty member to assure that course outcomes aligned with the safety outcomes to further clarify the vision.
Table 8: Chemical Engineering Faculty, Fall 2017 and Spring 2018 Courses, and Expertise

<table>
<thead>
<tr>
<th>Team Members</th>
<th>Course Taught</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarah Kostanski</td>
<td>2000, 3000, Co-op 1 &amp; Professional Issues</td>
<td>Co-op</td>
</tr>
<tr>
<td>Jacob Walker</td>
<td>2000, 3000, Co-op 1 &amp; Professional Issues</td>
<td>Co-op</td>
</tr>
<tr>
<td>Joshua Galloway</td>
<td>2308, Conservation Principles</td>
<td>Sustainability</td>
</tr>
<tr>
<td>Thomas Kinney</td>
<td>2308, 4510, Kinetics</td>
<td>Manufacturing</td>
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<tr>
<td>Barry Satvat</td>
<td>2310, 3322, 4510, Transport 1</td>
<td>Co-op/Education</td>
</tr>
<tr>
<td>Abby Koppes</td>
<td>2311, Lab 1</td>
<td>Health</td>
</tr>
<tr>
<td>Sidi Bencherif</td>
<td>2311, Lab 1</td>
<td>Health</td>
</tr>
<tr>
<td>Nasim Annabi</td>
<td>2311, Lab 1</td>
<td>Health</td>
</tr>
<tr>
<td>Adam Ekenseair</td>
<td>2320, Thermodynamics 1</td>
<td>Health</td>
</tr>
<tr>
<td>Julie Nguyen</td>
<td>3000, Professional Issues</td>
<td>Co-op</td>
</tr>
<tr>
<td>Rebecca Carrier</td>
<td>3312, Transport 2</td>
<td>Health</td>
</tr>
<tr>
<td>Lucas Landherr</td>
<td>3312, 4512, Transport 2 &amp; Process Control</td>
<td>Education</td>
</tr>
<tr>
<td>Courtney Pfluger</td>
<td>3313, Lab 2</td>
<td>Sustainability/Education</td>
</tr>
<tr>
<td>Ryan Koppes</td>
<td>3313, Lab 2</td>
<td>Health</td>
</tr>
<tr>
<td>Sunho Choi</td>
<td>3322, Thermodynamics 2</td>
<td>Sustainability</td>
</tr>
<tr>
<td>Francisco Hung</td>
<td>4701, Capstone 1, Separations</td>
<td>Sustainability/Health</td>
</tr>
<tr>
<td>Amit Roy</td>
<td>4703, Capstone Design 2</td>
<td>Health</td>
</tr>
<tr>
<td>Thomas Webster</td>
<td>4703, Capstone Design 2</td>
<td>Health</td>
</tr>
<tr>
<td>Ronald Willey</td>
<td>5699, 7262, Process Safety Special Topics</td>
<td>Security</td>
</tr>
</tbody>
</table>

Table 9: Fall 2017 Faculty Schedules

<table>
<thead>
<tr>
<th>Start Time</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
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<tbody>
<tr>
<td>8:00</td>
<td>3313</td>
<td>3313</td>
<td></td>
<td></td>
<td>2311</td>
</tr>
<tr>
<td>9:15</td>
<td>2310, 3312</td>
<td></td>
<td>2310, 3312</td>
<td>2310, 3312</td>
<td></td>
</tr>
<tr>
<td>9:50</td>
<td>4701</td>
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<td>4701</td>
<td>3000</td>
</tr>
<tr>
<td>10:30</td>
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<td></td>
<td>2000, 2310, 4512</td>
<td>2310, 4512</td>
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</tr>
<tr>
<td>11:45</td>
<td>2320, 3322, 4510</td>
<td>2000</td>
<td></td>
<td>2320, 3312, 4703</td>
<td>3000</td>
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<tr>
<td>1:35</td>
<td>2310, 3312, 4703</td>
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</tr>
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<td>3322</td>
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<td></td>
</tr>
<tr>
<td>4:35</td>
<td>2308, 4701</td>
<td></td>
<td>2308, 4701</td>
<td>2308, 4701</td>
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<tr>
<td>6:00</td>
<td>2311</td>
<td></td>
<td>2311, 3313</td>
<td></td>
<td></td>
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</tbody>
</table>
Table 10: Spring 2018 Faculty Schedules

<table>
<thead>
<tr>
<th>Start Time</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
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<td></td>
<td></td>
</tr>
<tr>
<td>9:15</td>
<td>3312, 4701</td>
<td></td>
<td>3312, 4701</td>
<td>3312, 4701</td>
<td></td>
</tr>
<tr>
<td>9:50</td>
<td>3312, 4510</td>
<td></td>
<td></td>
<td></td>
<td>3312, 4510</td>
</tr>
<tr>
<td>10:30</td>
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<td>4512</td>
<td></td>
<td>4512</td>
</tr>
<tr>
<td>11:45</td>
<td>3000</td>
<td></td>
<td>2320, 3312, 4703</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:35</td>
<td>2308, 4703</td>
<td>7262</td>
<td>2308, 4703</td>
<td>4703, 2311</td>
<td>2311</td>
</tr>
<tr>
<td>2:50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4:35</td>
<td>2308</td>
<td></td>
<td>2308</td>
<td></td>
<td>2308</td>
</tr>
<tr>
<td>6:00</td>
<td></td>
<td></td>
<td>2311, 5699</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 6: Sample Northeastern University Chemical Engineering Curriculum (up to the class of 2021 Five Years, Three Co-ops in Spring/Summer)
4.2 Policy

The method used to determine the policy for implementation, involved the change agent identifying current ABET and University/Department guidelines and resources, and then involving the stakeholders in evaluating and modifying department and course outcomes as appropriate. Stakeholder input is essential because top-down policies are not effective. The department ABET policies are the student outcomes. The course policies are the course outcomes. The ABET outcome changes needed to be accepted through a vote by the entire department. Course outcome changes needed to be accepted by the instructor.

The method for developing course policies involved discussions between the change agent and each faculty to align course outcomes with ABET and SACHe outcomes. These outcomes were then documented in the course syllabus and were measured through surveys and course assignments.

4.3 Curriculum

The method used to develop the curriculum was for the change agent to identify the concepts taught in the core course and identify aligning concepts in chemical process safety. The change agent then collaborated with each faculty to specify the course outcome, identify appropriate content to meet the outcome and the assessment tool. Collaboration is a key component of this method because developing and distributing curriculum is ineffective. The faculty must take ownership of the curriculum.

At the beginning and end of the Spring 2018 semester, students in the target courses were given two surveys. One to assess their process safety
knowledge and skills (Appendix 9.2) and another to assess their skills in the course outcome (Appendix 9.3). After each course, the students were given the same survey to measure the difference between the pre-and post-course safety implementation. These surveys were distributed to 409 students in eight courses.

4.4 Reflective Teachers

The method used for individual instructor reflection was the Northeastern University Chemical Engineering Department iAssess form. This form encourages faculty to reflect on the semester and identify strengths and areas for improvement. The iAssess has four parts, the first part asks the faculty to identify goals for the semester. The second part addresses whether or not student perceptions have changed about the course outcomes over the course of the semester. This is measured through pre-and post-surveys. The third part addresses whether or not the student have produced evidence that they have met the learning outcomes. This is measured through course grades on assignments that meet the course outcome. The fourth part is an analysis of the effectiveness of activities in the course. This give the instructor the opportunity to suggest future changes for the course. The iAssess form is located in Appendix 9.4.

In addition to the individual reflection, there was a group reflection. The change agent called a meeting of the group to reflect on the process of integration and the challenges encountered along the way.

Students were also asked to create a learning portfolio of their work and add the safety deliverables to the portfolio. This portfolio is an electronic document that utilizes the Digication e-portfolio software, which allows the students to save
evidence of their learning. An e-portfolio template with directions was developed for students. The main headings are organized by ABET outcome with subheadings for course outcomes, and space for students to attach copies of course work and a written reflection articulating how the work meets the outcome (Appendix 9.7).
5 Results and Discussion

This section examines the results of the process change methods and determines the effectiveness of process safety curriculum integration.

5.1 Vision

All of the information needed to form the vision was acquired through surveys with the Northeastern University IAB, Faculty, and through the Center for Chemical Process Safety interviews with women experienced in chemical process safety, as well as through informal personal interviews, attendance at chemical process safety workshops, ABET and AIChE conferences, and through literature sources such as ABET, and SACHE. This data allowed all the stakeholders to give input into developing the vision and defining the areas with the most significant need.

A summary of the needs assessment is listed in Table 11. The raw data for the table is listed in Appendix 9.5. At Northeastern University, over 20 faculty and 20 alumnae were surveyed, of those surveyed, seven alumnae and eight faculty responded. Through the Center for Chemical Process Safety, 11 of the 16 women interviewed answered. After reviewing the comments of everyone, it was evident that the eight SACHE outcomes covered all the specific examples that these groups identified. Understanding the importance of chemical process safety (1) was the most common response with 46% of all respondents identifying this as a critical learning outcome. The lowest response was understanding the consequences of incidents and a familiarity with regulations at a response rate of 15%. It is noted that some of this information may also be learned through studying
previous incidents (1). This evaluation didn’t identify any new outcomes beyond the SACHe recommended outcomes. Therefore, the SACHe outcomes and the incorporation of all eight outcomes was recommended.

Table 11: Needs Assessment

<table>
<thead>
<tr>
<th>SACHe Outcomes in Chemical Process Safety</th>
<th>% of Comments (Rank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The graduate must understand the importance of process safety and the resources and commitment required. This should include the important incidents that define process safety, and how these incidents affected the practice of chemical engineering.</td>
<td>46 (1)</td>
</tr>
<tr>
<td>2. The graduate should be familiar with the major regulations that impact the safety of chemical plants.</td>
<td>15 (6)</td>
</tr>
<tr>
<td>3. The graduate must be able to characterize the hazards associated with chemicals and other agents. This must include toxic, flammable, and reactive hazards.</td>
<td>27 (3)</td>
</tr>
<tr>
<td>4. The graduate should understand the consequences of chemical plant incidents due to acute and chronic chemical releases and exposures.</td>
<td>15 (5)</td>
</tr>
<tr>
<td>5. The graduate must understand and be able to apply concepts of inherently safer design.</td>
<td>19 (5)</td>
</tr>
<tr>
<td>6. The graduate must understand how to control and mitigate hazards to prevent accidents. This should include generally accepted management systems, plant procedures and designs to prevent accidents.</td>
<td>42 (2)</td>
</tr>
<tr>
<td>7. The graduate should be reasonably proficient with at least one hazard identification procedure.</td>
<td>42 (2)</td>
</tr>
<tr>
<td>8. The graduate should have an introduction to the process of hazard evaluation and risk assessment.</td>
<td>23 (4)</td>
</tr>
</tbody>
</table>

After identifying the necessary chemical process safety learning outcomes, the faculty that would implement these outcomes into their courses needed to be identified. There were 19 faculty teaching 12 core courses over two semesters.
After meeting with each faculty member to identify overlapping outcomes between the course and safety, the following team was formed (Figure 7):

1. PhD Candidate, Change Agent, Tracy Carter. Tracy Carter’s role was to coordinate all the efforts of the individual faculty members in the eight different courses to cover the eight-different chemical process safety learning outcomes, and provide technical support. She was also responsible for gathering all data and analyzing it to determine whether the aims of the dissertation had been met.

2. Conservation principles faculty Joshua Galloway and Thomas Kinney. Joshua Galloway is the DiPietro Assistant Professor, specializing in electrochemical engineering, batteries and energy storage, and energy sustainability. Thomas Kinney is an adjunct faculty member who is a MIT PhD Chemical Engineer--and Six Sigma Blackbelt--with many years successfully bringing new materials technologies into manufacturing.

3. Laboratory 1 faculty Abigail Koppes, Sidi Bencherif, Nasim Annabi. Abigail Koppes is an Assistant Professor, who’s research areas include bioelectric medicine, development of novel interventions and tissue engineered platforms for nerve regeneration and repair. Sidi Bencherif is an Assistant Professor, who specializes in polymer chemistry and characterization, new approaches to biomaterials design, injectable 3D polymer scaffolds, tissue engineering (e.g. liver, skin), controlled delivery of drugs/cells, and biomaterial-based cancer immunotherapies. Nasim Annabi is an Assistant
Professor, who’s interest lies in the areas of engineering advanced biomaterials for cardiovascular tissue engineering applications.

4. Professional Issues instructors Sarah Kostanski, Jacob Walker and Julie Kim Nguyen. Julie, Sarah and Jacob are Assistant Co-op Coordinators for chemical engineering. All hold advance degrees in engineering or related.

5. Transport Processes 2 faculty Lucas Landherr and Rebecca Carrier. Lucas Landherr is an associate Teaching Professor with expertise in engineering education, development of STEM comics to teach complex concepts and theory and production of research-inspired K-12 STEM experiments. Rebecca Carrier is the Professor & Associate Chair of Research with research in the areas of the interaction between biological systems and materials, with specific applications in drug delivery and regenerative medicine, as well as intestinal and retinal engineering and oral lipid systems.

6. Kinetics/reactor design faculty Thomas Kinney and Richard West. Richard West is an Assistant Professor, with research in the area of the development of detailed microkinetic models for complex reacting systems and automating the discovery and calculation of reaction pathways. Richard will not be teaching in the Spring of 2018, however this is a course that he typically teaches at least once an academic year, so he should be engaged in the process.

7. Process control faculty Lucas Landherr (background is described in item 5 above).
8. Capstone 1 faculty Francisco Hung. Francisco is an Associate Professor, specializing in molecular modeling of interfacial and solvated systems relevant to materials, manufacturing, energy and the environment.

9. Capstone 2 faculty Amit Roy and Thomas Webster. Amit Roy is an Assistant Teaching Professor, with a focus on nanomedicine research and technology development. He also generates international collaborations with various engineering research institutions/industries. Thomas Webster is a professor and Department Chair of Chemical Engineering & Art Zafiropoulo Chair in Engineering. His research interests include design, synthesis, and evaluation of nanomaterials for various medical applications, including self-assembled chemistries, nanoparticles, nanotubes, and nanostructured surfaces.

Figure 7: Organization of Team


5.2 Policy

After reviewing the ABET documentation, a new Chemical Engineering Department ABET student outcome was proposed. This outcome was presented to the faculty where there was a discussion and vote to change the previous student outcome to the new department ABET student outcome. This outcome has been posted on the department website and in the course catalog.

The previous outcome was: Upon graduation, graduates of the chemical engineering program shall have c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, **health and safety**, manufacturability, and sustainability.

The new outcome is: Upon graduation, graduates of the chemical engineering program shall have c) an ability to design a system, component, or chemical process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, manufacturability, and sustainability **as well as identifying and mitigating the hazards associated with that system, component or process to promote health and safety**.

Following the implementation of the new program ABET student outcome, the eight SACHÉ outcomes were mapped with the eleven ABET outcomes. Figure 8 illustrates how these outcomes align. Then these outcomes were individually discussed with each instructor to identify the appropriate course outcome for the core course. Table 12 lists the course outcomes for each core course and the related ABET and SACHÉ chemical process safety outcome.
Figure 8: Map of Potential Connections Between ABET Outcomes (yellow and green boxes, green is explicitly safety related and yellow are not explicitly safety related) to SACHE Chemical Process Safety Outcomes (white)
### Table 12: Chemical Process Safety Course Learning Outcomes Related to ABET and SACHIE Outcomes

<table>
<thead>
<tr>
<th>Course</th>
<th>Learning Outcome</th>
<th>ABET Criteria</th>
<th>SACHIE Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>2308 Conservation Principles</td>
<td>Combine and solve material and energy balances with physical and chemical data to address chemical engineering processes, including evaluating potential safety hazards.</td>
<td>c</td>
<td>3</td>
</tr>
<tr>
<td>2311 Chemical Engineering Lab1</td>
<td>Practice the ability to use the techniques, skills, and modern engineering tools necessary for chemical engineering practice.</td>
<td>k</td>
<td>3, 5, 6, 7</td>
</tr>
<tr>
<td>3000 Co-op 2</td>
<td>Explore ethical and safety issues in the workplace.</td>
<td>f</td>
<td>1</td>
</tr>
<tr>
<td>3000 Co-op 2</td>
<td>Investigate regulations common to the chemical engineering field.</td>
<td>h</td>
<td>2</td>
</tr>
<tr>
<td>3312 Transport 2</td>
<td>Assess hazards associated with heat &amp; mass transfer systems.</td>
<td>h</td>
<td>8</td>
</tr>
<tr>
<td>4510 Kinetics</td>
<td>Understand and appreciate safe design and operation of reactors.</td>
<td>f</td>
<td>3, 5, 6, 7</td>
</tr>
<tr>
<td>4512 Process Control</td>
<td>Design a process control system specifying component and instrumentation choices, so that the system is controlled and mitigates hazards.</td>
<td>c</td>
<td>6</td>
</tr>
<tr>
<td>4512 Process Control</td>
<td>Define, design and critique a layers of protection analysis for a process control system</td>
<td>k</td>
<td>7</td>
</tr>
<tr>
<td>4701 Separations: Capstone 1</td>
<td>Design a chemical plant that meets the engineering, economic and safety requirements defined by the marketplace and by relevant regulations (e.g., OSHA 1910.119)</td>
<td>e</td>
<td>2</td>
</tr>
<tr>
<td>4703 Design: Capstone 2</td>
<td>Understand roles of process safety, environmental protection, and society in the practice of chemical engineering.</td>
<td>f</td>
<td>1</td>
</tr>
<tr>
<td>4703 Design: Capstone 2</td>
<td>Appreciate the need for over-pressure protection of equipment and understand the related design practices.</td>
<td>c</td>
<td>4</td>
</tr>
<tr>
<td>4703 Design: Capstone 2</td>
<td>Prepare the preliminary process design to meet defined business, throughput, quality, and safety/environmental specifications.</td>
<td>e</td>
<td>3</td>
</tr>
</tbody>
</table>

The cognitive levels for the SACHIE outcomes were then identified (Table 13). The significant verb in each outcome was identified (underlined) then a level was assigned based on the verb and the context of the sentence. The level of learning for each course outcome was analyzed and the cognitive level was identified so that appropriate assessment tools could be used to determine to what
extent the outcome had been reached. Then the cognitive levels of the SAChE outcomes were compared to the course outcomes.

Table 13: SAChE Outcome Cognitive Learning Levels

<table>
<thead>
<tr>
<th>SAChE Outcomes in Chemical Process Safety</th>
<th>Cognitive Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The graduate must understand (describe) the importance of process safety and the resources and commitment required. This should include the important incidents that define process safety, and how these incidents affected the practice of chemical engineering.</td>
<td>Describe (1)</td>
</tr>
<tr>
<td>2. The graduate should be familiar with (describe) the major regulations that impact the safety of chemical plants.</td>
<td>Describe (1)</td>
</tr>
<tr>
<td>3. The graduate must be able to characterize (explain) the hazards associated with chemicals and other agents. This must include toxic, flammable, and reactive hazards.</td>
<td>Explain (2)</td>
</tr>
<tr>
<td>4. The graduate should understand (explain) the consequences of chemical plant incidents due to acute and chronic chemical releases and exposures.</td>
<td>Explain (2)</td>
</tr>
<tr>
<td>5. The graduate must understand and be able to apply concepts of inherently safer design.</td>
<td>Apply (3)</td>
</tr>
<tr>
<td>6. The graduate must understand (apply) how to control and mitigate hazards to prevent accidents. This should include generally accepted management systems, plant procedures and designs to prevent accidents.</td>
<td>Apply (3)</td>
</tr>
<tr>
<td>7. The graduate should be reasonably proficient (apply) with at least one hazard identification procedure.</td>
<td>Apply (3)</td>
</tr>
<tr>
<td>8. The graduate should have an introduction to (describe) the process of hazard evaluation and risk assessment.</td>
<td>Describe (1)</td>
</tr>
<tr>
<td>Course</td>
<td>Learning Outcome (ABET Criteria)</td>
</tr>
<tr>
<td>----------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2308 Conservation Principles</td>
<td>Combine and solve material and energy balances with physical and chemical data to address chemical engineering processes, including evaluating potential safety hazards. (c)</td>
</tr>
<tr>
<td>2311 Lab1</td>
<td>Practice the ability to use the techniques, skills, and modern engineering tools necessary for chemical engineering practice. (k)</td>
</tr>
<tr>
<td>3000 Professional Issues</td>
<td>Investigate regulations common to the chemical engineering field. (h)</td>
</tr>
<tr>
<td>3000</td>
<td>Explore ethical and safety issues in the workplace. (f)</td>
</tr>
<tr>
<td>3312 Transport 2</td>
<td>Assess hazards associated with heat &amp; mass transfer systems. (h)</td>
</tr>
<tr>
<td>4510 Kinetics</td>
<td>Understand and appreciate safe design and operation of reactors. (f)</td>
</tr>
<tr>
<td>4512 Process Control</td>
<td>Design a process control system specifying component and instrumentation choices, so that the system is controlled and mitigates hazards. (c)</td>
</tr>
<tr>
<td>4512</td>
<td>Define, design and critique a layers of protection analysis for a process control system. ©</td>
</tr>
<tr>
<td>4701 Separations: Capstone 1</td>
<td>Design a chemical plant that meets the engineering, economic and safety requirements defined by the marketplace and by relevant regulations (e.g., OSHA 1910.119). (k)</td>
</tr>
<tr>
<td>4703 Design: Capstone 2</td>
<td>Understand roles of process safety, environmental protection, and society in the practice of chemical engineering. (f)</td>
</tr>
<tr>
<td>4703</td>
<td>Appreciate the need for over-pressure protection of equipment and understand the related design practices. (h)</td>
</tr>
<tr>
<td>4703</td>
<td>Prepare the preliminary process design to meet defined business, throughput, quality, and safety/environmental specifications. (h)</td>
</tr>
</tbody>
</table>
It is evident when comparing the course outcome cognitive levels with the SACHe outcomes cognitive levels, that all the course outcomes met and exceeded the minimum cognitive level expectations (Table 14).

5.3 Curriculum

Eight chemical engineering chemical core courses implemented one or more of the eight SACHe outcomes. The following describes each outcome, the connection to the course (Figure 9) and the safety curriculum and the assessment that met the learning level.

Figure 9: The Connections Between Course Outcomes 1-8 (white), Core Courses with No Outcomes (orange), Core Courses with One Outcome (yellow), Core Courses with 2+ Outcomes (green).

The eight targeted courses in this dissertation were (Figure 10):

1. Sophomore level Conservation Principles
2. Sophomore/Middler level Laboratory 1
3. Middler/Junior level Transport 2
4. Middler/Junior level Professional Issues
5. Senior level Kinetics/Reactor Design
6. Senior level Process Control
7. Senior level Capstone 1
8. Senior level Capstone 2

Figure 10: Courses with Integrated Chemical Process Safety

The faculty teaching these courses had varying experience with chemical process safety and a minority had industrial experience. In order to match a learning outcome with a course, a meeting was conducted with each faculty member.
member to discuss the safety learning outcomes and the course outcomes. From those discussions, the course safety outcomes were specified. Following this collaborative effort, specific safety curriculum material was designed for each course and assignments were created (Appendix 9.8). The SAcHE outcome, course and description of activity and assessment are listed below.

1) **Describe the importance of process safety (Cognitive Level, CL 1).** Sources utilized were case studies supplied by the AIChE Process Safety Beacon and the US Chemical Safety Board:
   a) In the Professional Issues course, the students were introduced to several different chemical process safety incidents through a guest speaker. These incidents included an ammonia releases from the food industry and a dust explosion at a sugar manufacturing plant. The students were assigned a chemical process safety incident to investigate and they needed to describe (CL1) the incident, and the consequences in a presentation.
   b) In the senior level Capstone 2 course students must design a process. As part of the design, they needed to assess (CL5) the safety and health of their design and report it in a presentation and report.

2) **Describe major CPS regulations (CL1):**
   a) In the Professional Issues course, the students were introduced to regulations and they were assigned a chemical process safety incident to investigate. To demonstrate their knowledge, they needed to describe
(CL1) the incident, the consequences and the regulations that were relevant to the incident in a class presentation.

b) In the Capstone 1 course, the students were assigned a project to develop a chemical process. As part of that project, they needed to analyze (CL4) whether or not the OSHA standard 1910.119 (Process Safety Management of Highly Hazardous Chemicals) applied to their process and they had to deliver their information in a presentation and report.

3) Explain the chemical hazards (CL2):

a) In the Conservation Principles course, the students were introduced to the hazards associated with chemicals. They had to identify the hazards associated with ethylene oxide production on a homework assignment. For each chemical in the process they had to review the safety data sheet (SDS) and explain (CL2) the potential hazards for each material as specified by the American Conference of Governmental Industrial Hygienists (ACGIH) and the National Fire Protection Association (NFPA). Then they needed to explain (CL2) some of the key acronyms related to hazards, such as TLV, TWA, UFL and LFL, and LD$_{50}$ and LC$_{50}$.

b) In the Lab 1 course, students conducted five experiments over the course of the semester. As part of each proposal and report, the students needed to apply (CL3) the safety checklist to the particular experiment. This list required that the students acquire the SDS for each material in the experiment and identify the hazards associated with those chemicals.
c) In the senior level Kinetics course, students studied the T2 incident which was caused by a runaway reaction. They needed to identify (CL1) the hazards associated with the chemicals in the process.

d) In the senior level Capstone 2 course students must design a process. As part of the design, they needed to explain (CL2) the hazards associated with the chemicals in the process and report the results in a presentation and report.

4) **Explain** the consequences of chemical releases and exposures (CL2):
   In the Capstone 2 course, as part of the design project, students needed explain (CL2) the need for over-pressure protection of equipment and understanding the related design practices. This assessment was documented a presentation and report.

5) **Apply** methods of inherently safer design (CL3):
   a) In the Lab 1 course, in the final project, students design their own experiment. In their experiment proposal, they needed to write a safety analysis (CL4) justifying the choices of chemical for their experiment and employ methods of inherently safer design.
   
   b) In the senior level Kinetics course, students analyzed the process that lead to the T2 incident and identified (CL1) methods that would have made the process inherently safer.

6) **Apply** the control and mitigation techniques (CL3):
a) In the Lab 1 course, students designed their own experiment. In their experiment proposal, they needed to write a safety analysis \textit{(CL4)} applying control and mitigation of hazards.

b) In the senior level Kinetics course, students identified \textit{(CL1)} control and mitigation methods to mitigate the hazards identified in the T2 incident.

c) In Process Control, student groups designed \textit{(CL6)} a control system. They had to incorporate a process control schematic, develop transfer functions, and perform simulations of the process. They also had to add safety control measures into the design.

7) \textbf{Apply} procedures for hazard identification \textit{(CL3)}:

   a) In the Lab 1 course, students conduct their own experiments. In each experiment, they need to conduct a safety checklist analyze \textit{(CL4)} all the hazards associated with the experiment and report the results in their proposal and report.

   b) In the senior level Kinetics course, students identified \textit{(CL1)} hazard identification procedures that could have been used to prevent the T2 incident.

   c) In Process Control, students designed \textit{(CL4)} a control system and identified the hazards and the layers of protection to prevent the hazard.

8) \textbf{Describe} the processes for hazard evaluation and risk assessment \textit{(CL1)}:

   In Transport 2, a homework problem asked students to evaluate \textit{(CL5)} either a heat transfer or mass transfer unit in a process to determine what
could go wrong, what the consequences would be and how likely the event would happen.

5.4 Reflective Teachers

In order to reflect on the implementation of the SACHÉ outcomes into the core courses, the data needed to be analyzed. The measurements made were the assignment grades and the student perceptions before and after the course. The summary of the grades for all courses and all outcome is described in Figure 11. The grades are quantified on a 4.0 scale. All grades were above a 3.0 which indicates that the students were above the average expectation of the instructor. Pre-and post-course surveys were distributed to the students to measure their perception of their level of knowledge before and after the course (Figure 12). All perceptions increased. The three courses below 100% increase were Professional Issues (35-47%), Kinetics (32%), and Capstone 2 (25%).

Figure 11: Course Grades for Implementation of All SACHÉ Outcomes on a Scale from 1-4.
Below is a description of the SACHE outcomes and how they were implemented into the courses, along with the assignments, the grades on the assignments, and the average change in perception of the students in the course with respect to the specific course outcome. Table 15 is a summary of all the data.

1) Develop an understanding the importance of process safety:

a) In the junior level Professional Issues course, the students were introduced to several different chemical process safety incidents through a guest speaker. These incidents included an ammonia release from the food industry and a dust explosion at a sugar manufacturing plant. The students were assigned a chemical process safety incident to investigate and they needed to present the incident, and the consequences. The average score
for the student projects was a 3.9/4. Student perception scores increased 50% between the beginning and end of the semester.¹

b) In the senior level Capstone 2 course students designed a process. As part of the design, they needed to assess (CL5) the safety and health of their design and report it in a presentation and report. The average score for the student projects was a 4/4. Student perception scores increased 25% between the beginning and end of the semester.

2) Demonstrate an awareness of major CPS regulations:

a) In the junior level Professional Issues course, the students were assigned a chemical process safety incident to investigate and they needed to present the incident, the consequences and the regulations that were relevant to the incident. The average score for the student projects was a 3.9/4. Student perception scores increased 35% between the beginning and end of the semester.

b) In the senior level Capstone 1 course, the students were assigned a chemical process project and they needed to specify how OSHA standard 1910.119 (Process Safety Management of Highly Hazardous Chemicals) applied to their process through a presentation and report. The average score for the student projects was a 4/4. Student perception scores increased 120% between the beginning and end of the semester.

¹ The nature of these percentage increases reported, due to the small sample size involved, is good to only the nearest 5%. In some cases, the most positive results were rounded down to the nearest 10%.
3) Characterize chemical hazards:

a) In the sophomore level Conservation Principles course, the students were introduced to the hazards associated with chemicals. They had to identify the hazards associated with ethylene oxide production on a homework assignment. For each chemical in the process they had to review the safety data sheet (SDS) and list the potential hazards for each material as specified by the American Conference of Governmental Industrial Hygienists (ACGIH) and the National Fire Protection Association (NFPA). Then they needed to identify and define some of the key acronyms related to hazards, such as ACGIH TLV TWA, UFL and LFL, and LD50 and LC 50. The average score for the student projects was a 4/4. Student perception scores increased 150% between the beginning and end of the semester.

b) In the sophomore/middler level Lab 1 course, students conduct five experiments over the course of the semester. As part of their proposal and report, they need to complete a safety checklist. This list requires that the students acquire the SDS for each material in the experiment and identify the hazards associated with those chemicals. The average score for the student projects was a 3.7/4. Student perception scores increased 100% between the beginning and end of the semester.

c) In the senior level Kinetics course, students had to characterize the chemical hazards associated with the T2 incident. The average score for
the student projects was a 4/4. Student perception scores increased 32% between the beginning and end of the semester.

d) In the senior level Capstone 2 course students need to design a process. As part of the design, they need to identify the hazards associated with the chemicals in the process and report the results in a presentation and report. The average score for the student projects was a 4/4. Student perception scores increased 25% between the beginning and end of the semester.

4) Know the consequences of chemical releases and exposures:

In the senior level Capstone 2 course, as part of their design project, they need to specify the impact of a chemical release or exposure due to the chemicals in their process and report the results in a presentation and report. The average score for the student projects was a 4/4. Student perception scores increased 25% between the beginning and end of the semester.

5) Apply methods of inherently safer design:

a) In the sophomore/middler level Lab 1 course, students design their own experiment. In their experiment proposal, they need to write a safety analysis justifying the choices of chemical for their experiment and employ methods of inherently safer design. The average score for the student projects was a 3.7/4. Student perception scores were not measured.

b) In the senior level Kinetics course, students identified methods for making the T2 process inherently safer. The average score for the student
projects was a 4/4. Student perception scores increased 32% between the beginning and end of the semester.

6) Understand the control and mitigation of hazards:

   a) In the sophomore/middler level Lab 1 course, students design their own experiment. In their experiment proposal, they need to write a safety analysis applying control and mitigation of hazards. The average score for the student projects was a 3.7/4. Student perception scores increased 100% between the beginning and end of the semester.

   b) In the senior level Kinetics course, students identified control and mitigation methods that could have decreased the risk associated with the T2 process. The average score for the student projects was a 4/4. Student perception scores increased 32% between the beginning and end of the semester.

   c) In the senior level Process Control course, student groups designed a control system. They had to incorporate a process control schematic, develop transfer functions, and perform simulations of the process. They also had to add safety control measures into the design. The average score for the student projects was a 3.5/4. Student perception scores increased 150% between the beginning and end of the semester.

7) Conduct procedures for hazard identification:

   a) In the sophomore/middler level Lab 1 course, students conduct their own experiments. In each experiment, they need to conduct a safety checklist
identifying all the hazards associated with the experiment and report the results in their proposal and report.

b) In the senior level Kinetics course, students identified hazard identification procedures that could have been used to identify the hazards associated with the T2 process. **The average score for the student projects was a 4/4. Student perception scores increased 32% between the beginning and end of the semester.**

c) In the senior level Process Control course, students had to describe the layers of protection in their design. **The average score for the student projects was a 3.5/4. Student perception scores increased 150% between the beginning and end of the semester.**

8) Demonstrate processes for hazard evaluation and risk assessment:

In the junior level Transport 2 course, a homework problem asked students to evaluate either a heat transfer or mass transfer unit in a process to determine what could go wrong, what the consequences would be and how likely the event would happen. **The average score for the student projects was a 3/4. Student perception scores increased 110% between the beginning and end of the semester.**

Table 15 is a summary of all the data.

Students were also asked to submit a copy of their safety assessment to an electronic portfolio to demonstrate the knowledge and skills that they had acquired over the semester. All 409 students were given an in-class introduction to e-portfolios, the benefits were described and they were given access to the software
and the template for implementation. An electronic portfolio was created by 8% of all students. In Lab 1, 52% of students created an e-portfolio. It is predicted that this is primarily due to the fact that the faculty in this course offered extra credit for creating a portfolio. In the other courses the participation was noticeably lower. There was 3% participation in Conservation Principles, Professional Issues, Transport 2, Kinetics, Process Control and Capstone 1. There was zero percent participation in Capstone 2. Creating a portfolio takes time, and this was asked of the students at the end of the semester. Given how busy the end of the semester is for most students, it seems unlikely that they will participate unless given some incentive or can tangibly see the benefit.
<table>
<thead>
<tr>
<th>Course</th>
<th>Course Outcome</th>
<th>SAcHe Outcome</th>
<th>%Perception Change</th>
<th>Assignment Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation Principles</td>
<td>Combine and solve material and energy balances with physical and chemical data to address chemical engineering processes, including evaluating potential safety hazards.</td>
<td>3. Characterize the hazards associated with chemicals and other agents. This must include toxic, flammable, and reactive hazards.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport 1 Lab</td>
<td>Practice the ability to use the techniques, skills, and modern engineering tools necessary for chemical engineering practice. This will be assessed through completing certifications for Hazardous Waste, Chemical Hygiene 1&amp;2, writing technically accurate experimental procedures and methods, and through the submission of safety check-in and checkout sheets in the proposals, presentations and reports.</td>
<td>3. Characterize the hazards associated with chemicals and other agents. This must include toxic, flammable, and reactive hazards. 5. Apply concepts of inherently safer design. 6. Understand how to control and mitigate hazards to prevent accidents. This should include generally accepted management systems, plant procedures and designs to prevent accidents. 7. Proficient with at least one hazard identification procedure.</td>
<td>150</td>
<td>4</td>
</tr>
<tr>
<td>Professional Issues</td>
<td>Investigate regulations common to the chemical engineering field</td>
<td>2. Be familiar with the major regulations that impact the safety of chemical plants.</td>
<td>100</td>
<td>3.4</td>
</tr>
<tr>
<td>Professional Issues</td>
<td>Explore ethical and safety issues in the workplace</td>
<td>1. Understand important incidents that define process safety, and how these incidents affected the practice of chemical engineering.</td>
<td>35</td>
<td>3.9</td>
</tr>
<tr>
<td>Course</td>
<td>Course Outcome</td>
<td>SACChE Outcome</td>
<td>%Perception</td>
<td>Assignment</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>-------------</td>
<td>------------</td>
</tr>
<tr>
<td>Transport 2</td>
<td>Assess hazards associated with heat and mass transfer systems</td>
<td>8. Introduction to the process of hazard evaluation and risk assessment.</td>
<td>110</td>
<td>3</td>
</tr>
<tr>
<td>Kinetics</td>
<td>Understand and appreciate safe design and operation of reactors</td>
<td>3. Characterize the hazards associated with chemicals and other agents. This must include toxic, flammable, and reactive hazards. 5. Apply concepts of inherently safer design. 6. Understand how to control and mitigate hazards to prevent accidents. This should include generally accepted management systems, plant procedures and designs to prevent accidents. 7. Proficient with at least one hazard identification procedure.</td>
<td>32</td>
<td>4</td>
</tr>
<tr>
<td>Course</td>
<td>Course Outcome</td>
<td>SACEh Outcome</td>
<td>%Perception Change</td>
<td>Assignment Grade</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>--------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Process Control</td>
<td>Design a process control system specifying component and instrumentation choices, so that the system is controlled and mitigates hazards.</td>
<td>6. Understand how to control and mitigate hazards to prevent accidents. This should include generally accepted management systems, plant procedures and designs to prevent accidents.</td>
<td>150</td>
<td>3.5</td>
</tr>
<tr>
<td>Process Control</td>
<td>Define, design and critique a layers of protection analysis for a process control system.</td>
<td>7. Proficient with at least one hazard identification procedure.</td>
<td>150</td>
<td>3.5</td>
</tr>
<tr>
<td>Capstone 1</td>
<td>Design a chemical plant that meets the engineering, economic and safety requirements defined by the marketplace and by relevant regulations</td>
<td>2. Be familiar with the major regulations that impact the safety of chemical plants.</td>
<td>120</td>
<td>4</td>
</tr>
<tr>
<td>Capstone 2</td>
<td>Understand roles of process safety, environmental protection, and society in the practice of chemical engineering</td>
<td>1. Understand important incidents that define process safety, and how these incidents affected the practice of chemical engineering.</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>Capstone 2</td>
<td>Appreciate the need for over-pressure protection of equipment and understand the related design practices</td>
<td>4. Understand the consequences of chemical plant incidents due to acute and chronic chemical releases and exposures.</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>Capstone 2</td>
<td>Prepare the preliminary process design to meet defined business, throughput, quality, and safety/environmental specifications.</td>
<td>3. Characterize the hazards associated with chemicals and other agents. This must include toxic, flammable, and reactive hazards.</td>
<td>25</td>
<td>4</td>
</tr>
</tbody>
</table>
At the beginning and end of the Spring 2018 semester, students in the target courses were given a survey to assess their process safety knowledge and skills (Appendix 9.2). The survey was distributed to 409 students in eight courses. Of those students, 64 responded to both the pre-and post-surveys so that individual changes could be measured. The breakdown of the numbers by course is listed in Table 16. Of those students, it was noted that some took one chemical engineering course and some took up to four courses in the curriculum during the Spring semester (Table 17).

Table 16: Survey Response Numbers

<table>
<thead>
<tr>
<th>Course</th>
<th>Number of Students Responding to Both Pre/Post Survey</th>
<th>Total Students per Course</th>
<th>% Student Responding to Both</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation Principles</td>
<td>15</td>
<td>79</td>
<td>19</td>
</tr>
<tr>
<td>Lab 1</td>
<td>5</td>
<td>48</td>
<td>10</td>
</tr>
<tr>
<td>Professional Issues</td>
<td>8</td>
<td>77</td>
<td>10</td>
</tr>
<tr>
<td>Transport 2</td>
<td>13</td>
<td>69</td>
<td>19</td>
</tr>
<tr>
<td>Kinetics</td>
<td>17</td>
<td>122</td>
<td>14</td>
</tr>
<tr>
<td>Process Control</td>
<td>18</td>
<td>108</td>
<td>17</td>
</tr>
<tr>
<td>Capstone 1</td>
<td>7</td>
<td>69</td>
<td>10</td>
</tr>
<tr>
<td>Capstone 2</td>
<td>20</td>
<td>124</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 17: Number of Students Taking One or More Chemical Engineering Courses

<table>
<thead>
<tr>
<th>Number of Courses</th>
<th>Number of Students Taking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
Analyzing the pre-and post-surveys of each course, it was noted that Conservation Principles, Transport 2, and Capstone 1 student perceptions of safety increased (Figure 13). All three of these courses also noted greater than 100% increase in the course perceptions as well. It was noted that Lab 1 and Lab 2 both have values greater than 60%. Historically these two courses are perceived as having safety as part of their learning outcomes because the students are actually working in a laboratory with chemicals. It should be noted that Lab 2 was not included in the study because the course learning outcomes do not explicitly state safety; however, in practice, the safety expectations are the same as Lab 1. It is recommended that Lab 2 add an explicit safety learning outcome.

The perceived difference in the Professional Issues course decreased. It is not clear why. It also correlates with a less than 50% increase in perception in the course outcomes. Kinetics and Process control did not show a statistically significant increase. Kinetics also had a low perception in the course outcomes (32%). Process control, in general is perceived to contribute to process safety knowledge (60-80%) and students reported 150% increase in the course outcomes. Of those surveyed, greater than 50% of students perceive Capstone 2 as contributing to their process safety knowledge, there wasn’t a statistical difference measured, which is also reflected in the 25% perception in the course outcomes.

The three courses not included in the study, Transport 1, Thermodynamics 1 and Thermodynamics 2 all had perceptions below 25%, all others were reported above 40%. This indicates that just having the conversation with these students increases their awareness of chemical process safety.
Following the semester, there was a meeting to discuss the process and the impacts of the change implemented during the semester. In the discussions, the faculty identified the following areas for course improvement.

**Course recommendations for Fall 2018:**

1. Incorporate course outcomes that address safety into Lab 2 (Courtney Pfluger).
2. Add more specific safety expectations to the project in Conservation Principles and tie into the course outcomes.
3. Create a rubric for the measurement of safety outcomes for Lab 1 and Lab 2.
4. In Professional Issues, create a new lesson plan on regulations.
5. Specify the SACHE outcomes explicitly in the course syllabus.
7. In Kinetics, introduce the T2 incident and CSB video earlier in the semester so students understand the impact the fundamentals of kinetics have on the practice of chemical engineering.

8. Develop a better rubric for layers of protection in Process Control.

9. The project in Capstone 1 has multiple deliverables, including reports and presentations. The safety deliverables need to be independently assessed and reported rather than lumped into the total report or presentation assessment. Also, identifying the hazards associated with chemicals should be added as a course outcome because the students are already documenting the SDS of each chemical in the process.

10. In Capstone 2, it is not clear which safety outcomes were met based on the student project, because not all outcomes apply to every project. A safety checklist will be created for the students to identify which outcomes apply to their project.

5.5 Continuous Improvement Process Specifications

The following specifications were met for the continuous improvement process implemented during the Spring 2018 semester to implement chemical process safety across the curriculum:

- Must meet ABET requirements
- Process must be sustainable
- All SChE safety outcomes were incorporated across the curriculum
- Content can be easily integrated into the current chemical engineering courses by the faculty
• Content can be implemented for a fraction of the cost of an alternative solution such as the AIChE Chemical Process Safety Bootcamp

• Curriculum changes must be sustainable from academic year to academic year through the ABET continuous improvement process

• This methodology may be used for incorporating other curriculum initiatives into core courses, this may be applied to future initiatives such as integrated computer programming across the curriculum (Python is the current proposed computer programming language) and statistics.

5.6 Intellectual Property

The unique contribution of this dissertation was to develop and publish methods for successfully creating change in higher education and identify barriers that prevent change from occurring. Creating change in higher education is a new and emerging research field. Currently there is one reported model for facilitating change in the undergraduate curriculum, with few theories developed. This dissertation utilized this change model which draws upon established theories in diffusion of innovations, complexity leadership, and social network.

Integrating chemical process safety into the curriculum is an ABET requirement, and while there is a significant amount of published technical information specifying the chemical process safety curriculum, this information alone has not led to sweeping academic changes. Change is difficult. Making changes to the curriculum, given the fact that chemical engineering is not a new field, and that it has been taught at colleges and universities for over a hundred years, has high activation energy barriers. Typically, new content is introduced as a new elective course; however, new courses cannot be added
to the core curriculum because there are limitations on how many courses a student is required to take to graduate. Therefore, necessary changes in the curriculum due to the continuously evolving needs of industry and society must be integrated into existing courses.

Creating a methodology for change is essential for successfully implementing change in higher education. The candidate has also used this methodology to identify change needed in chemical process safety across universities in the chemical engineering laboratories. The candidate is working with four other universities to identify what is being taught and what can be taught. This work was published in the 2018 ASEE Conference Proceedings (Appendix 9.9).

This dissertation will serve as the basis for publication on the methodologies and strategies to integrate Chemical Process Safety into a Chemical Engineering Curriculum without the need for a new, separate course. The candidate also co-authored an article on Women in Chemical Process Safety for Process Safety Progress (in press), which further articulates the urgent need for more engineers to enter the field of chemical process safety and the article identifies methods for students to get the necessary knowledge and skills to work in the field of chemical process safety.

5.7 Sustainability

To ensure the sustainability of this chemical process safety curriculum change, the process was documented in the ABET Continuous Improvement Process. This process and the individual accountability is documented in Appendix 9.10.
5.8 Economics

The financial value of this research was determined by identifying the financial impact of not making the necessary curriculum changes and calculating return on investment. Northeastern University is a private urban institution which has a total undergraduate enrollment of 13,473. Undergraduate tuition and fees are $49,497 (2017-18) per year,\(^{56}\) which leads to annual tuition revenue of around $670 million. The university is ranked in the top 50 of Best Colleges as reported by US News and World Reports and it has a 29% acceptance rate.\(^{18}\) In general, the more students, the more income for the university, and more students in a program means more funds are allocated to that program. Loss of accreditation due to a lack of meeting ABET criteria would impact those values. The Chemical Engineering department has 550 undergraduate students; a loss of students would lead to a loss of up to $27 million dollars in annual tuition.

To maintain accreditation, chemical process safety must be integrated into the curriculum. One method would be to hire external experts to teach the content. AIChE sponsors a student chemical process safety boot camp. The boot camp is a one weekend program, led by industry and chemical engineering faculty experts. This boot camp services 20 students and costs $20,000.\(^{57}\) The cost to cover all 550 students would be $550,000 and an annual cost of $140,000. The cost of one graduate student to implement chemical process safety across the curriculum for one year is $35,000. This leads to a return on investment (ROI) of >1500% for the first year (assuming all 550 students need to be enrolled) and a ROI of 300% for each subsequent year for each incoming class of 140 students.
6 Conclusions

Failure to prepare students with essential process safety training can and does lead to catastrophic events. In the Spring of 2018, the Northeastern University Chemical Engineering program integrated process safety across the curriculum.

The eight SACHE learning outcomes were integrated in eight different courses. The effectiveness of the process as measured through student perception surveys before and after the curriculum showed a minimum of a 25% increase and a maximum of 150% increase in knowledge and skills, and the material that the students delivered for each course scored greater than 3.7 ± 0.3/4.0. This dissertation was successful because: 1. The faculty developed a shared vision on chemical process safety. 2. Chemical process safety curriculum policy was enacted through Student and Course Outcomes 3. The faculty were able to disseminate chemical process safety curriculum. 4. Faculty were able to reflect on the results and propose future changes to create a continuous improvement process (Figure 14).

The curriculum and course outcomes were developed and aligned with the eight recommended SACHE outcomes. These eight outcomes include understanding past events, the hazards and impacts of chemicals and releases, as well as understanding how to assess the hazards and risks associated with a process and to design or mitigate against them. Each outcome was incorporated into at least one of the eight core courses.

The ultimate result of this dissertation is a sustainable process for integrating chemical process safety across the curriculum. Curriculum integration of content is essential due to program credit limits, which limit the number of new core courses that can be added to the curriculum. This process incorporates all SACHE safety outcomes,
meets ABET safety requirements, allows any new content to be easily integrated by faculty into the core curriculum and can be implemented for a fraction of the cost of alternatives such as the AIChE Chemical Process Safety Bootcamp. In addition, as a result of this dissertation, two publications were produced.

Figure 14: Chemical Engineering Curriculum Continuous Improvement Process
7 Future Work

Following the work done during academic year 2017-18, faculty feedback, and resultant student deliverables, the faculty identified the following areas for course improvement.

Course recommendations for Fall 2018:

1. Incorporate course outcomes that address safety into Lab 2 (Courtney Pfluger).
2. Add more specific safety expectations to the project in Conservation Principles and tie into the course outcomes.
3. Create a rubric for the measurement of safety outcomes for Lab 1 and Lab 2.
4. In Professional Issues, create a new lesson plan on regulations.
5. Add another homework problem in Transport 2.
6. In Kinetics, introduce the T2 incident and CSB video earlier in the semester so students understand the impact the fundamentals of kinetics have on the practice of chemical engineering.
7. Develop a better rubric for LOPA analysis in Process Control.
8. The project in Capstone 1 has multiple deliverables, including reports and presentations. The safety deliverables need to be independently assessed and reported rather than lumped into the total report or presentation assessment. Also, identifying the hazards associated with chemicals should be added as a course outcome because the students are already documenting the SDS of each chemical in the process.
9. In Capstone 2 there are many safety outcomes that could be met based on the student project, because not all apply to every project. A safety checklist will be created for the students to identify which outcomes apply to their project.

These recommendations will be passed onto the teaching faculty August 1, 2018 through the iAssess forms, and followed up with a face-to-face meeting with the faculty on September 4, 2018. In order to provide more reflective and planning time for the faculty, in addition to the spring education retreat, a fall education retreat will be scheduled for December 2018. In terms of budgeting for next year, it is recommended that breakfast and lunch ($500 for 25 faculty for two meals) should be provided for these two education retreats. Therefore, $1,000 should be added to the budget proposal in November.

After graduation, the candidate will continue working with the Safety and Chemical Engineering Education (SACHe) committee to improve chemical engineering chemical process safety education across all colleges and universities. As part of the SACHe initiatives, she is co-chairing a safety and education session at the 2018 AIChE annual meeting. In the Fall of 2018, she will further develop safety education in the unit operations laboratory in collaboration with the University of Maryland, the University of Minnesota Twin-Cities, and Washington University. In the summer of 2019, she will teach a Dialog of Civilization with Prof. Ronald Willey in Tarragona, Spain on Chemical Process Safety.
8 References


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56. University, N. Cost and Financial Aid. [https://www.northeastern.edu/admissions/cost/](https://www.northeastern.edu/admissions/cost/)
57. AICHE Student Process Safety Bootcamp. [https://www.aiche.org/giving/events/ccps-student-bootcamp/2017-08-17](https://www.aiche.org/giving/events/ccps-student-bootcamp/2017-08-17)
9 Appendices

9.1 Definitions

ABET: The accreditation board for education and technology

ABET Program Curriculum Criteria: “The curriculum must provide a thorough grounding in the basic sciences including chemistry, physics, and/or biology, with some content at an advanced level, as appropriate to the objectives of the program. The curriculum must include the engineering application of these basic sciences to the design, analysis, and control of chemical, physical, and/or biological processes, including the hazards associated with these processes.”

ABET Student Outcomes, Criterion 3: “The program must have documented student outcomes that prepare graduates to attain the program educational objectives. Student outcomes are outcomes (a) through (k) plus any additional outcomes that may be articulated by the program.

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

(d) an ability to function on multidisciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary
for engineering practice."

AIChe: American Institute of Chemical Engineering, based in New York, NY
CPS: Chemical Process Safety
CCPS: Center for Chemical Process Safety

Course Outcome: What a student is able to demonstrate upon completing a course, this is
documented in the course syllabus

Learning Outcome: What a student is able to demonstrate upon completion of learning

SAChe: Safety and Chemical Engineering Education Committee
SAChe CPS fundamentals: February 2010 SAChe recommendations for chemical
process safety knowledge and skills that meet ABET curriculum requirements: 3

1. Develop an understanding of the importance of process safety
2. Demonstrate an awareness of major chemical process safety regulations
3. Characterize chemical hazards
4. Know the consequences of chemical releases and exposures
5. Apply methods of inherently safer design
6. Understand the control and mitigation of hazards
7. Conduct procedures for hazard identification
8. Demonstrate processes for hazard evaluation and risk assessment
9.2 Chemical Process Safety Survey

NOTE: Please send survey feedback to Tracy Carter at Northeastern University: t.carter@northeastern.edu

The purpose of this survey is to identify specific overlapping needs from various stakeholders in chemical process safety education. Your feedback will help us understand your experience and knowledge of chemical process safety and identify which concepts of chemical process safety you interact with on an academic or professional level.

This survey will focus on recommendations by the Safety and Chemical Engineering Education (SACHE) Committee, within the Center for Chemical Process Safety (CCPS). SACHE has recommended the following 8 concepts, which meet ABET university accreditation requirements for undergraduate students:

1. Understand the importance of process safety and the resources and commitment required.
2. Understand the impacts of chemical plant incidents due to releases and exposures.
3. Be familiar with major safety related regulations.
4. Characterize the hazards associated with chemicals.
5. Be proficient with at least one hazard identification procedure.
6. Understand how to mitigate hazards.
7. Apply concepts of inherently safer design.
8. Be familiar with hazard evaluation and risk assessment.

We would appreciate 7 minutes of your time to complete this survey to help us identify the need in chemical process safety education so that universities can make effective curriculum changes in chemical process safety.
What is your current professional role?

- Undergraduate Student
- Graduate Student
- Faculty
- Industry
- Other (Please Specify) 

Other Block

1 of 13. What industry sector do you have the most experience in (choose the best answer)?

- Food
- Energy, Sustainability
- Health, Pharmaceuticals, Biotechnology
- Materials
- Processes
- Safety, Security
- Other (Please Specify) 

2 of 13. Where or how did you gain that professional experience? 


3 of 13. How many years of experience do you have in that sector?
Questions 4-12

For the following questions please indicate your perspective on chemical process safety concepts based on your cumulative academic and professional experiences.

4 of 13. In my experience, with respect to the importance of chemical process safety, I notice:

☐ Safety isn’t a priority unless someone is caught
☐ Safety is important and accidents are addressed
☐ Safety is important and hazards are pro-actively mitigated
☐ Safety is built into the culture and everything is considered based on inherently safer design
☐ I do not have experience dealing with safety related issues

5 of 13. In my experience with respect to understanding the impacts of chemical plant incidents (you may choose multiple answers):

☐ I have read about incidents outside of my state
☐ I have read about incidents inside my state
☐ I have been a bystander to an incident(s)
☐ I have been involved in an incident(s)
☐ I am not aware of any incidents
6 of 13. In my experience, I am aware of the following major safety-related regulations and agencies (you may choose multiple answers):

- EPIC Environmental Protection Agency
- European Seveso
- India: The Factories Act
- Mexico: NORMA Official Mexicana NOM-026-STPS-2004
- NFPA: National Fire Protection Agency
- OSHA: Occupational Safety and Health Administration
- United Kingdom: Health and Safety Executive: Control of Major Accident Hazards (COMAH)
- Other: 
- I do not have experience with this.

7 of 13. In my professional experience, I have worked with the following chemical hazards (you may choose multiple answers):

- Health Hazard:
  - Flammable
  - Carcinogen
  - Mutagen
  - Toxicity
  - Explosive
  - Skin or Eye Irritant
  - Heating
  - Pyrogenic
  - Reproductive
  - Enflin
  - Toxicity
  - Respiratory Sensitizer
  - Infectious Substances
  - Radioactive Substances
- I do not have experience working with hazardous chemicals.

8 of 13. I have used the following hazard identification procedures (you may choose multiple answers):
9 of 13. I have used the following methods to mitigate hazards (you may choose multiple answers):

- Countermeasures (examples: sprays, curtains, dilution, foams, or deliberate ignition)
- Emergency Response Systems (examples: personal protective equipment, emergency procedures)
- Engineering Design (examples: plant and process integrity, emergency process design, spill containment)
- Management (examples: policies, procedures, maintenance and testing, security)
- Sensors and Detectors (examples: sensors and detectors with alarms)
- I do not have experience with this

10 of 13. I have used these inherently safer design methods (you may choose multiple answers):

- Minimize (examples: use smaller quantities and/or size of equipment)
- Isolate (examples: operate at less hazardous conditions)
- Simplify (examples: design a user-friendly process)
- Substitute (examples: use less hazardous materials, chemical, and/or processes)
- I do not have experience with this
11 of 13. Typically in a hazard evaluation and risk assessment, I have identified (you may choose multiple answers):

- What can go wrong
- How bad could it be
- How often might it happen
- I do not have experience with this

12 of 13. Please feel free to suggest any other chemical process safety knowledge, skills or attributes necessary for undergraduate students’ professional development:

13 of 13. Which of the following experiences have added to your process safety knowledge and skills? Check all that apply:

- Introduction to Engineering Co-op
- Conservation Principles
- Transport Processes 1
- Thermodynamics 1
- Transport Lab 1
- Transport Processes 2
- Thermodynamics 2
- Transport Lab 2 (Heat Transfer and Separations)
- Professional Issues in Engineering
- Chemical Engineering Kinetics
- Process Control
- Capstone 1
- Capstone 2
- Safety Courses
- Internship (Please specify all that apply)
- Co-op company (Please specify all that apply)
- Other (Please specify all that apply)
9.3 Example of Pre-and Post-Course Outcome Survey

Pre-Semester Survey

CHME 2311 Pre Semester Survey Spring 2018

This survey is currently LOCKED to prevent invalidation of collected responses. Please unlock your survey to make changes.

Q1 Please complete the following pre-course assessment. The purpose of this assessment is to determine your current level of knowledge and abilities with respect to the knowledge and abilities you should obtain by the end of the course.

Q2 Please describe your current abilities. Depending on your life experiences, you may or may not have any experience with these outcomes. It is expected that by the end of this course you will have increased your current abilities in all these areas.

Choose how well each of the following statements describes you:
5: Extremely Well
4: Very Well
3: Moderately Well
2: Slightly Well
1: Not At All

<table>
<thead>
<tr>
<th></th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
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<tr>
<td>2.</td>
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<td>3.</td>
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<td>4.</td>
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<td>5.</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Q3 What are you looking forward to in this course?

Q4 What are you concerned about in this course?
Post Semester Survey

CHME 2311 Post Semester Survey

Please complete the following post course assessment. The purpose of this assessment is to determine your current level of knowledge and abilities after completing this course.

**Q2** Please rate your current level of knowledge.

<table>
<thead>
<tr>
<th></th>
<th>Describes me extremely well</th>
<th>Describes me very well</th>
<th>Describes me moderately well</th>
<th>Describes me slightly well</th>
<th>Does not describe me</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Able to identify needs (problems) and then design and conduct engineering experiments in the area of fluid transport, to meet the desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, or sustainability. (SOC 4 b)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2. Able to use the techniques, skills, and modern engineering tools necessary in the area of fluid transport for chemical engineering practice. (SOC 4 a)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3. Able to apply knowledge of mathematics, science, and engineering to analyze and interpret data and information to solve engineering problems within the field of transport phenomena with an emphasis on fluid flow. (SOC 4 a)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4. Able to communicate effectively through written and oral presentations. (SOC 4 g)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5. Able to contribute to a project as part of a team. (SOC 4 d)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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</tbody>
</table>

**Q3** What aspects of this course were beneficial to your professional development?


**Q4** What course changes would you recommend?


**Import Questions From...**  **Create a New Question**
9.4 Sample Course iAssess Document

Instructor’s Assessment
CHME 2308 Conservation Principles in Chemical Engineering

Semester / Year: Spring / 2018  Instructor: Your Name  Section: 01  Date: 4/29/2018

This assessment form is based on the set of topics and course learning outcomes listed in the ABET 2-Pager and course syllabus. Do not change your stated learning outcomes without consulting with the UEC first.

Expectations regarding this course assessment:

a. _____ Before the start of the course, I have reviewed the previous instructor assessments for recommendations on how to improve the course. Click on the box to verify that you have reviewed the previous documents.

b. _____ Before the start of the course, I am aware of the need to conduct start- and end-of-semester student self-assessment surveys. Click on the box to verify this statement.

c. _____ I am aware that I need to list the Course Outcomes and the ABET SO’s from the ABET 2-pager for this course in my syllabus. Click on the box to verify this statement.

d. _____ I am aware that I need to map scores for individual assignments/quizzes/exams to each course outcome. Click on the box to verify this statement.

e. _____ I have listed the Course Outcome and the associated ABET Student Outcomes (SO’s) from my course syllabus in Sections 2 and 3 of this form (this may already be done for you see below). Click on the box to verify this statement.

f. _____ Complete the form and save it as a Word document with filename like this: IAssess_CHME2308_FALL2017_XXX. (XXX your initials)

g. _____ This form needs to be uploaded to the SharePoint Site under the Course Repository and under the Semester Folder within 2 weeks after the end of final exams. Also, please make sure that your course syllabus has been uploaded.

Link to Share Point
1. What course improvements did you make? How successful were they? Relate them to recommendations made in previous course assessments. Expand the table as necessary.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1.</td>
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<td>2.</td>
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<td>3.</td>
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</tbody>
</table>
2. The Course Outcomes listed below must appear on your start- and end-of-semester student self-assessment surveys$^2$ and be scored using a 1-5 system.

1: none  2: minimal  3: average  4: good  5: excellent

Instructor comments are your response to student comments from the self-assessment survey or departmental TRACE evaluation: Please respond to serious criticisms and suggestions.

<table>
<thead>
<tr>
<th>Course Outcomes (Associated ABET Student Outcome/SO)</th>
<th>Student Self-Assessment</th>
<th>Instructor Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start-of-Semester</td>
<td>End-of-Semester</td>
</tr>
<tr>
<td>1. Express process variables representing pressure, temperature, composition, and flow rates in different unit systems and express the role of dimensionality. (SO 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Evaluate, estimate, and interpret data for process variables, including following rules for significant figures. (SO 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Implement material balances to describe batch, continuous, and semi-batch processes based on drawing and labeling a process flow sheet and performing a degree-of-freedom analysis. (SO 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Formulate material balances for multiple unit operation processes, including processes with recycle, bypass, and purge streams, based on overall balances and balances on independent subunits. (SO 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Express and solve material balances for reactive processes, including combustion processes with different types of feed of oxygen, in terms of molecular and atomic species balances and extent of reaction. (SO 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Use physical chemical descriptions for solids, liquids, gases, and their mixtures and solutions to solve material balances. (SO 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Express energy balances for closed and open systems. (SO e)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Apply mechanical energy balances, including their simplification as the Bernoulli equation, to address flow problems. (SO-1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Combine and solve material and energy balances with physical and chemical data to address chemical engineering processes, including evaluating potential safety hazards. (SO-1))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Identify and communicate real world engineering research topics. (SO-3,7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Write professional memos to communicate engineering ideas. (SO-3)</td>
<td></td>
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</tr>
</tbody>
</table>

$^2$ Student self-assessments surveys available on SharePoint.
3. **Below are the Course Outcomes that are listed on the course syllabus.** For each, give an assessment of the students’ ability to meet that specific outcome. "Basis for assessment" should be "#xxx" where xxx is the listed homework/project/exam that measures that outcome. Changes to course outcomes and SOs require teaching cluster approval.

Average scores if multiple questions are used for evaluation of outcome comprehension. Convert letter grades to 4-point scale. (A=4, B=3, C=2, D=1, F=0)

<table>
<thead>
<tr>
<th>Course Outcomes</th>
<th>ABET SO’s</th>
<th>Basis for Assessment</th>
<th>Average Score (from homework, project, exam etc.)</th>
<th>Comments for teaching cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Express process variables representing pressure, temperature, composition, and flow rates in different unit systems and express the role of dimensionality.</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Evaluate, estimate, and interpret data for process variables, including following rules for significant figures.</td>
<td></td>
<td>1</td>
<td></td>
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<tr>
<td>3. Implement material balances to describe batch, continuous, and semi-batch processes based on drawing and labeling a process flow sheet and performing a degree-of-freedom analysis.</td>
<td></td>
<td>1</td>
<td></td>
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<tr>
<td>4. Formulate material balances for multiple unit operation processes, including processes with recycle, bypass, and purge streams, based on overall balances and balances on independent subunits.</td>
<td></td>
<td>1</td>
<td></td>
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<tr>
<td>5. Express and solve material balances for reactive processes, including combustion processes with different types of feed of oxygen, in terms of molecular and atomic species balances and extent of reaction.</td>
<td></td>
<td>1</td>
<td></td>
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<tr>
<td>6. Use physical chemical descriptions for solids, liquids, gases, and their mixtures and solutions to solve material balances.</td>
<td></td>
<td>1</td>
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<tr>
<td>7. Express energy balances for closed and open systems.</td>
<td></td>
<td>1</td>
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<tr>
<td>8. Apply mechanical energy balances, including their simplification as the Bernoulli equation, to address flow problems.</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Combine and solve material and energy balances with physical and chemical data to address chemical engineering processes, including evaluating potential safety hazards.</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Identify and communicate real world engineering research topics.</td>
<td>3,7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Write professional memos to communicate engineering ideas.</td>
<td>3,7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. Recommendations for improving this course. Relate the recommendations to TRACE comments, Student Self-Assessment comments and/or results from the course outcomes assessment. Expand the table as needed.

<p>| | | |</p>
<table>
<thead>
<tr>
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<tbody>
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<td>2.</td>
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<tr>
<td>3.</td>
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</tbody>
</table>
ABET Student Outcomes (SO) Criterion 3

Upon graduation, graduates of the chemical engineering program shall have…
a)…an ability to apply knowledge of mathematics, science, and engineering in the general field of chemical engineering.
b)…an ability to design and conduct engineering experiments, as well as analyze and interpret data.
c)…an ability to design a system, component, or chemical process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, manufacturability, and sustainability as well as identifying and mitigating the hazards associated with that system, component or process to promote health and safety.
d)…an ability to function on teams, including multi-disciplinary teams.
e)…an ability to identify, formulate, and solve chemical engineering problems.
f)…an understanding of professional and ethical responsibility; this includes protecting the public and the environment by performing their work in a safe and environmentally conscious manner.
g)…an ability to communicate effectively.
h)…the broad education necessary to understand the impact of engineering solutions in a global and societal context.
i)…a recognition of the need for and the ability to engage in lifelong learning.
j)…an understanding of professional behavior, culture, expectations, and contemporary issues.
k)…an ability to use the techniques, skills, and modern engineering tools necessary for chemical engineering practice.
As revised by the ABET EAD on October 20, 2017 the student outcomes numbering and scope were changed slightly beginning for the 2019-20 cycle. The faculty of the Northeastern Department of Chemical Engineering reviewed and adopted revisions to its student outcomes on March 27, 2018. These were reviewed by the UEC and approved on March 21, 2018. Discussed by the IAB on April 19, 2018. They were implemented into the program during the Spring 2018 semester. There are no substantial changes compared to the previous outcomes SO a-k.

The program must have documented student outcomes that support the program educational objectives. Attainment of these outcomes prepares graduates to enter the professional practice of engineering.

The Department of Chemical Engineering Student Outcomes are outcomes (1) through (7):

SO-1. An ability to identify, formulate, and solve complex chemical engineering problems by applying principles of engineering, science, and mathematics (formerly SO a, e, and k).

SO-2. An ability to apply chemical engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors as well as identifying and mitigating the hazards associated with that design to promote health and safety (formerly SO c and k).

SO-3. An ability to communicate effectively with a range of audiences (formerly SO g).

SO-4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts including protecting the public and the environment by performing their work in a safe and environmentally conscious manner. (formerly SO f, h, and j).

SO-5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives (formerly SO d).

SO-6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions (formerly SO b and k).

SO-7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies (formerly SO i).
Program Educational Objectives (PEO)

Within a few years after graduation, graduates of the chemical engineering program are expected to obtain the ability to…

1. function successfully in a variety of fields in chemical engineering or in advanced study that uses the problem-solving skills taught in chemical engineering.
2. identify problems, collect necessary information, and analyze data to draw appropriate conclusions, and make informed decisions.
3. function effectively in a diverse workplace using interpersonal and communicative skills gained from their chemical engineering training
4. recognize an economic, environmental, health and safety, or sustainability situation in need of improvement, then, make suggestions that improve this situation.
### 9.5 Safety Needs Assessment

Please feel free to suggest any other chemical process safety knowledge, skills or attributes necessary for undergraduate students' professional development:

<table>
<thead>
<tr>
<th>Faculty (8 Responses)</th>
<th>SACChE Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Umm.... normal safety training? Not sure exactly what you're going for here.</td>
<td>6</td>
</tr>
<tr>
<td>layers of protect</td>
<td>8</td>
</tr>
<tr>
<td>How process controls, both manual and automatic, can mitigate process related safety and hazard risks.</td>
<td></td>
</tr>
<tr>
<td>Safety training</td>
<td></td>
</tr>
<tr>
<td>Case studies</td>
<td>1, 4, 6, 8</td>
</tr>
<tr>
<td>I find it very difficult to assess if students are properly trained in safety, even after going through standard training, I find students still do not know how to safely operate in a research environment.</td>
<td>6</td>
</tr>
<tr>
<td>There are really multiple aspects to safety ranging from the engineering &amp; manufacturing process safety to the daily TAKE-TWO (think before you act) mentality. Normally the daily issues cause more frequent, usually-less serious injuries in research environments. Both limits need to be taught and practiced before we can say that we have created a safety culture.</td>
<td>6</td>
</tr>
<tr>
<td>I teach FMEA as a guide for product safety and effectiveness. This would be a good technique for evaluating process safety for operators (students) if all the tenets are fully utilized.</td>
<td>7</td>
</tr>
<tr>
<td>Day to day safety as well as process safety</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>Safety assessment</td>
<td>6, 8</td>
</tr>
</tbody>
</table>
Please feel free to suggest any other chemical process safety knowledge, skills or attributes necessary for undergraduate students' professional development:

<table>
<thead>
<tr>
<th>Alumnae (7 Responses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>teaching the T1 reactor explosion in Kinetics was interesting perspective. I think it'd be valuable for students to study actual incidents and see where tools like HAZOP, FMEA, etc., would be helpful.</td>
</tr>
<tr>
<td>Additionally, students should be taught how to use service firms that determine reactivity of substances....thinking of like Chilworth Technology. A conference-room setting and the internet are generally not sufficient to HAZOP a process with innovative unique situations &amp; actual physical testing of chemicals/materials involved is a must.</td>
</tr>
<tr>
<td>Root Cause Analysis done by Apollo Associates</td>
</tr>
<tr>
<td>Studying of Past Incidents</td>
</tr>
<tr>
<td>Per my comments at today's IAB Meeting, use of Behavior Based Safety Observations enables safety to become more deeply integrated into an organization's culture. This occurs because with random, ongoing observations and sharing, safety awareness shifts from an on/off mode to a continuous mode. Analyses of BBSO's can also reveal trends, leading to further opportunities for hazard mitigation.</td>
</tr>
<tr>
<td>Regulatory awareness including OSHA PSM, the design of intrinsically/inherently safe systems, environmental impact risk as a result of an incident.</td>
</tr>
<tr>
<td>Knowledge and experience is critical, but it is worthless without the courage to intervene - sometimes despite significant pressure to start-up a new chemical process or plant, or simply operate an existing facility/unit.</td>
</tr>
<tr>
<td>Lock-out/Tag-out confined space</td>
</tr>
<tr>
<td>Understanding a MSDS, conducting a mock FMEA, and having a general introduction to safe process design.</td>
</tr>
<tr>
<td>Please feel free to suggest any other chemical process safety knowledge, skills or attributes necessary for undergraduate students' professional development:</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td><strong>Women in Process Safety (11 Responses)</strong></td>
</tr>
<tr>
<td>Process safety should be taught at every level. There should be guest speakers to talk about the importance. Students should know how to do a HAZOP.</td>
</tr>
<tr>
<td>Students should know how to design a robust system, they should know how to use HAZOP and What-if procedures, they should also know LOPA.</td>
</tr>
<tr>
<td>Students should listen to an industry panel discuss the need and watch CSB videos of incidents. Process safety should be a core course and integrated at every level. Students should study the hazards associated with chemicals, study minimization, mitigation as part of design, and know how to use checklists and JSA’s and understand risk</td>
</tr>
<tr>
<td>Chemical Process Safety should be integrated at every level of the curriculum</td>
</tr>
<tr>
<td>Students should understand dispersion modeling and HAZOP</td>
</tr>
<tr>
<td>Students should study examples of incidents and understand the big picture because process safety is about the system</td>
</tr>
<tr>
<td>Chemical process safety should be interdisciplinary. Students should understand the hazards of chemicals, mitigation of hazards and they should be able to perform a what if analysis.</td>
</tr>
<tr>
<td>Students should understand the importance of Chemical Process Safety and they should understand the regulations.</td>
</tr>
<tr>
<td>Students should understand the value of Chemical Process Safety</td>
</tr>
<tr>
<td>Chemical Process Safety should be interdisciplinary</td>
</tr>
<tr>
<td>Students should simulate events and determine hazardous consequences. Chemical Process Safety should be a core course. Students should study runaway reactions and know how to do a HAZOP and JSA.</td>
</tr>
</tbody>
</table>
9.6 Course iAssess Forms

The following are an example and excerpts from the IASSESS forms submitted by each faculty member from each course identifying chemical process safety course outcomes and results. The full IASSESS forms include all course outcomes, however for the sake of brevity, only the safety information was included.

9.6.1 CHME 2308 Conservation Principles

**Semester / Year:** Spring 2018

**Instructor:** Thomas Kinney  
**Section:** 01  
**Date:** 4/29/2018

This assessment form is based on the set of topics and course learning outcomes listed in the ABET 2-Pager and course syllabus. Do not change your stated learning outcomes without consulting with the UEC first.

1. What course improvements did you make? How successful were they? Relate them to recommendations made in previous course assessments. *Expand the table as necessary.*

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Did a project...really thought this was great, well received</td>
</tr>
<tr>
<td>2.</td>
<td>Had in-class problem solving...I think this was very helpful for students, to solidify the lecture knowledge</td>
</tr>
<tr>
<td>3.</td>
<td>Had quizzes. Had too few!</td>
</tr>
</tbody>
</table>

2. The Course Outcomes listed below must appear on your start- and end-of-semester student self-assessment surveys and be scored using a 1-5 system.  
1: none  
2: minimal  
3: average  
4: good  
5: excellent  

Instructor comments are your response to student comments from the self-assessment survey or departmental TRACE evaluation: *Please respond to serious criticisms and suggestions.*

<table>
<thead>
<tr>
<th>Course Outcomes (Associated ABET Student Outcome/SO)</th>
<th>Student Self-Assessment</th>
<th>Instructor Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start-of-Semester (average of all respondents)</td>
<td>End-of-Semester (average of all respondents)</td>
</tr>
<tr>
<td>Combine and solve material and energy balances with physical and chemical data to address chemical</td>
<td>1.48</td>
<td>3.80</td>
</tr>
</tbody>
</table>

---

3 Student self-assessments surveys available on SharePoint.
3. Below are the Course Outcomes that are listed on the course syllabus. For each, give an assessment of the students’ ability to meet that specific outcome. “Basis for assessment” should be “#xxx” where xxx is the listed homework/project/ exam that measures that outcome. Changes to course outcomes and SOs require teaching cluster approval.

Average scores if multiple questions are used for evaluation of outcome comprehension. Convert letter grades to 4-point scale. (A=4, B=3, C=2, D=1, F=0)

<table>
<thead>
<tr>
<th>Course Outcomes</th>
<th>ABET SO’s</th>
<th>Basis for Assessment</th>
<th>Average Score (from homework, project, exam etc.)</th>
<th>Comments for teaching cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combine and solve material and energy balances with physical and chemical data to address chemical engineering processes, including evaluating potential safety hazards.</td>
<td>1</td>
<td>Final project (&amp; one assignment question)</td>
<td>A</td>
<td>The final project had students dig deep into a chemical engineering scenario. Additionally, safety aspects were evaluated with an assignment question). ** note: seems like this should be two separate outcomes.</td>
</tr>
</tbody>
</table>

4. Recommendations for improving this course. Relate the recommendations to TRACE comments, Student Self-Assessment comments and/or results from the course outcomes assessment. Expand the table as needed.

11. Thought the project was a great way to end the course, but it probably should be re-designed to avoid copying to next semester’s students.
This assessment form is based on the set of topics and course learning outcomes listed in the ABET 2-Pager and course syllabus. Do not change your stated learning outcomes without consulting with the UEC first.

1. What course improvements did you make? How successful were they? Relate them to recommendations made in previous course assessments. Expand the table as necessary.

4. I added an overview lecture on chem-e, given on powerpoint and dealing with the scope of chem-e. I think it went well.

2. The Course Outcomes listed below must appear on your start- and end-of-semester student self-assessment surveys and be scored using a 1-5 system.

1: none  2: minimal  3: average  4: good  5: excellent

Instructor comments are your response to student comments from the self-assessment survey or departmental TRACE evaluation: Please respond to serious criticisms and suggestions.

<table>
<thead>
<tr>
<th>Course Outcomes (Associated ABET Student Outcome/SO)</th>
<th>Student Self-Assessment</th>
<th>Instructor Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start-of-Semester (average of all respondents)</td>
<td>End-of-Semester (average of all respondents)</td>
</tr>
<tr>
<td></td>
<td>1.68</td>
<td>4.14</td>
</tr>
</tbody>
</table>

Combine and solve material and energy balances with physical and chemical data to address chemical engineering processes, including evaluating potential safety hazards. (SO-1))

3. Below are the Course Outcomes that are listed on the course syllabus. For each, give an assessment of the students’ ability to meet that specific outcome. “Basis for assessment” should be “#xxx” where xxx is the listed homework/project/exam that measures that outcome. Changes to course outcomes and SOs require teaching cluster approval.

---

4 Student self-assessments surveys available on SharePoint.
Average scores if multiple questions are used for evaluation of outcome comprehension. Convert letter grades to 4-point scale. (A=4, B=3, C=2, D=1, F=0)

<table>
<thead>
<tr>
<th>Course Outcomes</th>
<th>ABET SO's</th>
<th>Basis for Assessment</th>
<th>Average Score (from homework, project, exam etc.)</th>
<th>Comments for teaching cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combine and solve material and energy balances with physical and chemical data to address chemical engineering processes, including evaluating potential safety hazards.</td>
<td>1</td>
<td>Final Exam</td>
<td>82/100</td>
<td></td>
</tr>
</tbody>
</table>

4. Recommendations for improving this course. Relate the recommendations to TRACE comments, Student Self-Assessment comments and/or results from the course outcomes assessment. Expand the table as needed.

11. Thought the project was a great way to end the course, but it probably should be re-designed to avoid copying to next semester’s students.
9.6.2  CHME 2311 Transport Lab 1

**Semester / Year:** Spring / 2018

**Instructor:** Nasim Annabi  
**Section:** 01  
**Date:** 5/10/2018

This assessment form is based on the set of topics and course learning outcomes listed in the ABET 2-Pager and course syllabus. Do not change your stated learning outcomes without consulting with the UEC first.

1. **What course improvements did you make? How successful were they? Relate them to recommendations made in previous course assessments.** *Expand the table as necessary.*

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Continued using the safety check-in/out sheets that were developed last semester. The students needed to include images of themselves and their work area to ensure safe attire and working area. This worked well to increase awareness of their surroundings.</td>
</tr>
</tbody>
</table>
2. The Course Outcomes listed below must appear on your start- and end-of-semester student self-assessment surveys\(^5\) and be scored using a 1-5 system.

1: none  2: minimal  3: average  4: good  5: excellent

Instructor comments are your response to student comments from the self-assessment survey or departmental TRACE evaluation: Please respond to serious criticisms and suggestions.

<table>
<thead>
<tr>
<th>Course Outcomes (Associated ABET Student Outcome/SO)</th>
<th>Student Self-Assessment</th>
<th>Instructor Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start-of-Semester</td>
<td>End-of-Semester</td>
</tr>
<tr>
<td></td>
<td>(average of all</td>
<td>(average of all</td>
</tr>
<tr>
<td></td>
<td>respondents)</td>
<td>respondents)</td>
</tr>
<tr>
<td>2. Practice the ability to use the techniques,</td>
<td>NA</td>
<td>4.7</td>
</tr>
<tr>
<td>skills, and modern engineering tools necessary for</td>
<td></td>
<td></td>
</tr>
<tr>
<td>chemical engineering practice. This will be</td>
<td></td>
<td></td>
</tr>
<tr>
<td>assessed through completing certifications for</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hazardous Waste, Chemical Hygiene 1&amp;2, writing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>technically accurate experimental procedures and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>methods, and through the submission of safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>check-in and checkout sheets in the proposals,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>presentations and reports.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^5\) Student self-assessments surveys available on SharePoint.
3. Below are the Course Outcomes that are listed on the course syllabus. For each, give an assessment of the students’ ability to meet that specific outcome. “Basis for assessment” should be “#xxx” where xxx is the listed homework/project/exam that measures that outcome. Changes to course outcomes and SOs require teaching cluster approval.

Average scores if multiple questions are used for evaluation of outcome comprehension. Convert letter grades to 4-point scale. (A=4, B=3, C=2, D=1, F=0)

<table>
<thead>
<tr>
<th>Course Outcomes</th>
<th>ABET SO's</th>
<th>Basis for Assessment</th>
<th>Average Score (from homework, project, exam etc.)</th>
<th>Comments for teaching cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Practice the ability to use the techniques, skills, and modern engineering tools necessary for chemical engineering practice. This will be assessed through completing certifications for Hazardous Waste, Chemical Hygiene 1&amp;2, writing technically accurate experimental procedures and methods, and through the submission of safety check-in and checkout sheets in the proposals, presentations and reports.</td>
<td>1</td>
<td>Proposals, reports and presentations</td>
<td>3.8</td>
<td></td>
</tr>
</tbody>
</table>

4. Recommendations for improving this course. Relate the recommendations to TRACE comments, Student Self-Assessment comments and/or results from the course outcomes assessment. Expand the table as needed.

11 Create a grading system that addresses outcomes and allows for easy computation for IASSESS.
This assessment form is based on the set of topics and course learning outcomes listed in the ABET 2-Pager and course syllabus. Do not change your stated learning outcomes without consulting with the UEC first.

1. What course improvements did you make? How successful were they? Relate them to recommendations made in previous course assessments. *Expand the table as necessary.*

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Update slides for the lectures – students had access to more useful tips for the experiments</td>
</tr>
<tr>
<td>2.</td>
<td>Revise guidelines and syllabus – students were able to use more frequently to follow the course</td>
</tr>
<tr>
<td>3.</td>
<td>Kept the team members in the same groups all semester, instead of switching so they had more time to work on group communication and dynamics.</td>
</tr>
<tr>
<td>4.</td>
<td>Starting offering incentive for students taking surveys – increased number of participants</td>
</tr>
<tr>
<td>5.</td>
<td>Giving feedback for reports and proposals within a week and discuss about my comments and common mistakes in the class – students improved the quality of their writing.</td>
</tr>
</tbody>
</table>
2. The Course Outcomes listed below must appear on your start- and end-of-semester student self-assessment surveys\(^6\) and be scored using a 1-5 system.
1: none 2: minimal 3: average 4: good 5: excellent

Instructor comments are your response to student comments from the self-assessment survey or departmental TRACE evaluation: Please respond to serious criticisms and suggestions.

<table>
<thead>
<tr>
<th>Course Outcomes (Associated ABET Student Outcome/SO)</th>
<th>Student Self-Assessment</th>
<th>Instructor Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start-of-Semester</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(average of all</td>
<td></td>
</tr>
<tr>
<td></td>
<td>respondents)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>End-of-Semester</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(average of all</td>
<td></td>
</tr>
<tr>
<td></td>
<td>respondents)</td>
<td></td>
</tr>
<tr>
<td>2. Practice the ability to use the techniques, skills, and modern engineering tools necessary for chemical engineering practice. This will be assessed through completing certifications for Hazardous Waste, Chemical Hygiene 1&amp;2, writing technically accurate experimental procedures and methods, and through the submission of safety check-in and checkout sheets in the proposals, presentations and reports.</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

\(^6\) Student self-assessments surveys available on SharePoint.
3. **Below are the Course Outcomes that are listed on the course syllabus.** For each, give an assessment of the students’ ability to meet that specific outcome. "Basis for assessment" should be "#xxx" where xxx is the listed homework/project/exam that measures that outcome. Changes to course outcomes and SOs require teaching cluster approval.

Average scores if multiple questions are used for evaluation of outcome comprehension. Convert letter grades to 4-point scale. (A=4, B=3, C=2, D=1, F=0)

<table>
<thead>
<tr>
<th>Course Outcomes</th>
<th>ABET SO's</th>
<th>Basis for Assessment</th>
<th>Average Score (from homework, project, exam etc.)</th>
<th>Comments for teaching cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice the ability to use the techniques, skills, and modern engineering tools necessary for chemical engineering practice. This will be assessed through completing certifications for Hazardous Waste, Chemical Hygiene 1&amp;2, writing technically accurate experimental procedures and methods, and through the submission of safety check-in and checkout sheets in the proposals, presentations and reports.</td>
<td>1</td>
<td>Proposals, reports and presentations</td>
<td>B</td>
<td></td>
</tr>
</tbody>
</table>

4. **Recommendations for improving this course.** Relate the recommendations to TRACE comments, Student Self-Assessment comments and/or results from the course outcomes assessment. Expand the table as needed.

1. *Provide more information on their report/presentation templates*
2. *Create a rubric for each deliverable*
9.6.3 CHME 3000 Professional Issues in Engineering

Semester / Year: Spring / 2018  Instructor: Sarah K., Julie N., Jake W.  Section: 01  Date: 4/29/2018

This assessment form is based on the set of topics and course learning outcomes listed in the ABET 2-Pager and course syllabus. Do not change your stated learning outcomes without consulting with the UEC first.

1. **What course improvements did you make? How successful were they?** Relate them to recommendations made in previous course assessments. Expand the table as necessary.

1. Changed the order of the content and assignments to best meet student needs.

2. The Course Outcomes listed below must appear on your start- and end-of-semester student self-assessment surveys\(^7\) and be scored using a 1-5 system.

1: none  2: minimal  3: average  4: good  5: excellent

Instructor comments are your response to student comments from the self-assessment survey or departmental TRACE evaluation: Please respond to serious criticisms and suggestions.

<table>
<thead>
<tr>
<th>Course Outcomes (Associated ABET Student Outcome/SO)</th>
<th>Student Self-Assessment</th>
<th>Instructor Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigate regulations common to the chemical engineering field (SO-2)</td>
<td>Start-of-Semester: 2.62  End-of-Semester: 3.85</td>
<td></td>
</tr>
<tr>
<td>Explore ethical and safety issues in the workplace (SO-4)</td>
<td>Start-of-Semester: 3.07  End-of-Semester: 4.14</td>
<td>Will work on covering more ethical issues in the future.</td>
</tr>
</tbody>
</table>

**Student Comments from Self-Assessment Survey & TRACE**

**Learning Related Questions:**

1. I enjoyed the resume, cover letter, and career assignments. The safety talk was inspirational and helpful in determining how I can impact my future workplace.

8. The safety and ethics discussions were probably the only topics of value for me. Video documentaries were not effective at conveying the importance of safety and the ethics discussions were limited.

---

\(^7\) Student self-assessments surveys available on SharePoint.
3. **Below are the Course Outcomes that are listed on the course syllabus.** For each, give an assessment of the students’ ability to meet that specific outcome. “Basis for assessment” should be “#xxx” where xxx is the listed homework/project/exam that measures that outcome. Changes to course outcomes and SOs require teaching cluster approval.

Average scores if multiple questions are used for evaluation of outcome comprehension. Convert letter grades to 4-point scale. (A=4, B=3, C=2, D=1, F=0)

<table>
<thead>
<tr>
<th>Course Outcomes</th>
<th>ABET SO's</th>
<th>Basis for Assessment</th>
<th>Average Score (from homework, project, exam etc.)</th>
<th>Comments for teaching cluster</th>
</tr>
</thead>
</table>
| 12. Investigate regulations common to the chemical engineering field            | 2         | (1) Team Presentations  
(2) Attend class presentations/speakers/panels  
(3) Process Safety presentation by Rich Sarnie | (1) 3.9  
(2) N/A  
(3) N/A |                              |
| 13. Explore ethical and safety issues in the workplace                          | 4         | (1) Team Presentations  
(2) Attend class presentations/speakers/panels  
(3) Ethics case studies during class | (1) 3.9  
(2) N/A  
(3) N/A |                              |
4. Recommendations for improving this course. Relate the recommendations to TRACE comments, Student Self-Assessment comments and/or results from the course outcomes assessment. Expand the table as needed.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Add more case studies covering morally gray issues in the workplace.</em></td>
</tr>
<tr>
<td>2</td>
<td><em>Change team presentation team topics (focus on social/cultural issues in the workplace). Still need to make sure we address: “Explore ethical and safety issues in the workplace.”</em></td>
</tr>
<tr>
<td>5</td>
<td><em>More explicit introduction to regulatory bodies per outcome “Investigate regulations common to the CHME field”. Explicitly communicate the 2 SACHÉ outcomes this class is trying to address: “The graduate must understand the importance of process safety and the resources and commitment required. This should include the important incidents that define process safety, and how these incidents affected the practice of chemical engineering.” &amp; “The graduate should be familiar with the major regulations that impact the safety of chemical plants.”</em></td>
</tr>
</tbody>
</table>
9.6.4 CHME 3312 Transport 2

Semester / Year: Spring / 2018  Instructor: Lucas Landherr  Section: 01  Date: 5/13/2018

This assessment form is based on the set of topics and course learning outcomes listed in the ABET 2-Pager and course syllabus. Do not change your stated learning outcomes without consulting with the UEC first.

1. **What course improvements did you make? How successful were they?** Relate them to recommendations made in previous course assessments. *Expand the table as necessary.*

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
| 1. | Continued the course project from the previous semester with the purpose of providing more learning material to students based on their own creations.  
Most students did not make use of the material, as they were hesitant to influence their own course projects. This essentially backfired as a project, to some degree. Will need to reassess how to approach this project in future semesters. |

2. The Course Outcomes listed below must appear on your start- and end-of-semester student self-assessment surveys and be scored using a 1-5 system.
1: none  2: minimal  3: average  4: good  5: excellent

Instructor comments are your response to student comments from the self-assessment survey or departmental TRACE evaluation: *Please respond to serious criticisms and suggestions.*

<table>
<thead>
<tr>
<th>Course Outcomes (Associated ABET Student Outcome/SO)</th>
<th>Student Self-Assessment</th>
<th>Instructor Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start-of-Semester</td>
<td>End-of-Semester</td>
</tr>
<tr>
<td>14. assess hazards associated with heat &amp; mass transfer systems (h)</td>
<td>2.00 ± 0.88</td>
<td>4.19 ± 0.89</td>
</tr>
</tbody>
</table>

3. **Below are the Course Outcomes that are listed on the course syllabus.** For each, give an assessment of the students’ ability to meet that specific outcome. “Basis for assessment” should be “#xxx” where xxx is the listed homework/project/ exam that measures that outcome. Changes to course outcomes and SOs require teaching cluster approval.

---

8 Student self-assessments surveys available on SharePoint.
Average scores if multiple questions are used for evaluation of outcome comprehension. Convert letter grades to 4-point scale. (A=4, B=3, C=2, D=1, F=0)

<table>
<thead>
<tr>
<th>Course Outcomes</th>
<th>ABET SO's</th>
<th>Basis for Assessment</th>
<th>Average Score (from homework, project, exam etc.)</th>
<th>Comments for teaching cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>14. assess hazards associated with heat &amp; mass transfer systems (h)</td>
<td>h</td>
<td>HW#8 Q5</td>
<td>80.0%</td>
<td></td>
</tr>
</tbody>
</table>

4. Recommendations for improving this course. Relate the recommendations to TRACE comments, Student Self-Assessment comments and/or results from the course outcomes assessment. Expand the table as needed.

2. Need to revisit how to integrate the deliverables of previous course projects into the course better to get more students to use the course work.
9.6.5 CHME 4510 Kinetics

Semester / Year: Spring / 2018  Instructor: Thomas Kinney  Section: 01  Date: 4/29/2018

This assessment form is based on the set of topics and course learning outcomes listed in the ABET 2-Pager and course syllabus. Do not change your stated learning outcomes without consulting with the UEC first.

1. What course improvements did you make? How successful were they? Relate them to recommendations made in previous course assessments. Expand the table as necessary.

| 6 | Tracked participation by BB surveys |

2. The Course Outcomes listed below must appear on your start- and end-of-semester student self-assessment surveys\(^9\) and be scored using a 1-5 system.

1: none  2: minimal  3: average  4: good  5: excellent

Instructor comments are your response to student comments from the self-assessment survey or departmental TRACE evaluation: Please respond to serious criticisms and suggestions.

<table>
<thead>
<tr>
<th>Course Outcomes (Associated ABET Student Outcome/SO)</th>
<th>Student Self-Assessment</th>
<th>Instructor Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start-of-Semester</td>
<td>End-of-Semester</td>
</tr>
<tr>
<td>15. Understand and appreciate safe design and operation of reactors (SO-2).</td>
<td>2.08</td>
<td>3.71</td>
</tr>
</tbody>
</table>
3. Below are the Course Outcomes that are listed on the course syllabus. For each, give an assessment of the students’ ability to meet that specific outcome. “Basis for assessment” should be “#xxx” where xxx is the listed homework/project/ exam that measures that outcome. Changes to course outcomes and SOs require teaching cluster approval. Average scores if multiple questions are used for evaluation of outcome comprehension. Convert letter grades to 4-point scale. (A=4, B=3, C=2, D=1, F=0)

<table>
<thead>
<tr>
<th>Course Outcomes</th>
<th>ABET SO's</th>
<th>Basis for Assessment</th>
<th>Average Score (from homework, project, exam etc.)</th>
<th>Comments for teaching cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>15. 1. Understand and appreciate safe design and operation of reactors.</td>
<td>2</td>
<td>Quiz in latter part of course</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

4. Recommendations for improving this course. Relate the recommendations to TRACE comments, Student Self-Assessment comments and/or results from the course outcomes assessment. Expand the table as needed.

I like a project to end the course, however, expectations have to be clear and students have to be enthusiastic and attend others presentations as well. Again, tracking attendance, participation, etc. would be helpful.
9.6.6 CHME 4512 Process Control

Semester / Year: Spring / 2018  Instructor: Lucas Landherr  Section: 01  Date: 5/13/2018

This assessment form is based on the set of topics and course learning outcomes listed in the ABET 2-Pager and course syllabus. Do not change your stated learning outcomes without consulting with the UEC first.

1. What course improvements did you make? How successful were they? Relate them to recommendations made in previous course assessments. Expand the table as necessary.

2. The Course Outcomes listed below must appear on your start- and end-of-semester student self-assessment surveys and be scored using a 1-5 system.

   1: none   2: minimal   3: average   4: good   5: excellent

   Instructor comments are your response to student comments from the self-assessment survey or departmental TRACE evaluation: Please respond to serious criticisms and suggestions.

<table>
<thead>
<tr>
<th>Course Outcomes (Associated ABET Student Outcome/SO)</th>
<th>Student Self-Assessment</th>
<th>Instructor Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start-of-Semester</td>
<td>End-of-Semester</td>
</tr>
<tr>
<td>12) Design a process control system specifying component and instrumentation choices, so that the system is controlled and mitigates hazards. 16.</td>
<td>1.54 ± .74</td>
<td>3.96 ± .77</td>
</tr>
<tr>
<td>13) Define, design and critique a layers of protection analysis for a process control system. 17.</td>
<td>1.49± .82</td>
<td>3.75 ± .74</td>
</tr>
</tbody>
</table>

3. Below are the Course Outcomes that are listed on the course syllabus. For each, give an assessment of the students’ ability to meet that specific outcome. “Basis for assessment” should be “#xxx” where xxx is the listed homework/project/ exam that measures that outcome. Changes to course outcomes and SOs require teaching cluster approval.

---

Student self-assessments surveys available on SharePoint.

---
Average scores if multiple questions are used for evaluation of outcome comprehension. Convert letter grades to 4-point scale. (A=4, B=3, C=2, D=1, F=0)

<table>
<thead>
<tr>
<th>Course Outcomes</th>
<th>ABET SO's</th>
<th>Basis for Assessment</th>
<th>Average Score (from homework, project, exam etc.)</th>
<th>Comments for teaching cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>12) Design a process control system specifying component and instrumentation choices, so that the system is controlled and mitigates hazards.</td>
<td>C</td>
<td>Problem Set #7, Project</td>
<td>89.2%</td>
<td></td>
</tr>
<tr>
<td>13) Define, design and critique a layers of protection analysis for a process control system.</td>
<td>K</td>
<td>Project</td>
<td>89.7%</td>
<td>Will develop a better rubric for next semester to allow for better analysis of this data point.</td>
</tr>
</tbody>
</table>

4. Recommendations for improving this course. Relate the recommendations to TRACE comments, Student Self-Assessment comments and/or results from the course outcomes assessment. Expand the table as needed.

1. *Need to integrate Simulink earlier into the course without allowing the ‘autotune’ option to overpower the need to work out solutions by hand.*
2. *Begin working towards physical hands-on equipment, possibly through Arduino kits.*
3. *Eliminate the pre-requisite to help make this course available for students earlier in their curriculum.*
1. What course improvements did you make? How successful were they? Relate them to recommendations made in previous course assessments. *Expand the table as necessary.*

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><em>Improved planification of class topics (in Fall 2017 started with separations and Aspen Plus, then covered economics and got a period of three classes at the end of the semester where we came back to separations – students didn’t like that). This semester I covered separations, Aspen Plus and safety topics first, then covered economics until the end of the semester.</em></td>
</tr>
</tbody>
</table>

2. The Course Outcomes listed below must appear on your start- and end-of-semester student self-assessment surveys and be scored using a 1-5 system.

   1: none  2: minimal  3: average  4: good  5: excellent

Instructor comments are your response to student comments from the self-assessment survey or departmental TRACE evaluation: Please respond to serious criticisms and suggestions.

<table>
<thead>
<tr>
<th>Course Outcomes (Associated ABET Student Outcome/SO)</th>
<th>Student Self-Assessment</th>
<th>Instructor Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design a chemical plant that meets the engineering, economic, and safety requirements defined by the marketplace and by relevant regulations (e.g., OSHA 1910.119). (SO 2)</td>
<td>Start-of-Semester: 1.88</td>
<td>End-of-Semester: 4.16</td>
</tr>
</tbody>
</table>

3. Below are the Course Outcomes that are listed on the course syllabus. For each, give an assessment of the students’ ability to meet that specific outcome. “Basis for assessment” should be “#xxx” where xxx is the listed homework/project/exam that measures that outcome. Changes to course outcomes and SOs require teaching cluster approval. Average scores if multiple questions are used for evaluation of outcome comprehension. Convert letter grades to 4-point scale. (A=4, B=3, C=2, D=1, F=0)

---

11 Student self-assessments surveys available on SharePoint.
<table>
<thead>
<tr>
<th>Course Outcomes</th>
<th>ABET SO’s</th>
<th>Basis for Assessment</th>
<th>Average Score (from homework, project, exam etc.)</th>
<th>Comments for teaching cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Design a chemical plant that meets the engineering, economic and safety</td>
<td>2</td>
<td>Presentation 1</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>requirements defined by the marketplace and by relevant regulations (e.g., OSHA</td>
<td></td>
<td>Presentation 2</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>1910.119). (SO 1)</td>
<td></td>
<td>Presentation 3</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Draft report</td>
<td>A-</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final report</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

4. Recommendations for improving this course. Relate the recommendations to TRACE comments, Student Self-Assessment comments and/or results from the course outcomes assessment. Expand the table as needed.

1. *I still need to think more on how to make these Aspen Plus classes to be more like a ‘training session’ in a computer lab (but in the same classroom with the students using their laptops via Virtual Lab). Also make classes more interactive.*

2. *A big improvement will come when the material on theory of separations is transferred to Lab2. One could then focus on using Aspen Plus, process evaluation and simulation, and economics. Topics such as heat recovery in processes, sensitivity analysis, modeling processes with solids, etc. are not covered at all because the course is very loaded with material right now.*
1. Invited NEU-alumni to talk about their experience. Students liked the approach
2. Business Executives from Sanofi & Pfizer lined up for next semester.
3. Industry experts & CEOs were invited to discuss their experience. Student enjoyed it and they reviewed some open positions.

2. The Course Outcomes listed below must appear on your start- and end-of-semester student self-assessment surveys\(^\text{12}\) and be scored using a 1-5 system.
   1: none  2: minimal  3: average  4: good  5: excellent
   Instructor comments are your response to student comments from the self-assessment survey or departmental TRACE evaluation: Please respond to serious criticisms and suggestions.

<table>
<thead>
<tr>
<th>Course Outcomes (Associated ABET Student Outcome/SO)</th>
<th>Student Self-Assessment</th>
<th>Instructor Comment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start-of-Semester</td>
<td>End-of-Semester</td>
</tr>
<tr>
<td>Understand roles of process safety, environmental</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>protection, and society in the practice of chemical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>engineering (f).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appreciate the need for over-pressure protection of</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>equipment and understand the related design practices (c).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepare the preliminary process design to meet defined</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>business, throughput, quality, and safety/environmental</td>
<td></td>
<td></td>
</tr>
<tr>
<td>specifications (e).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Below are the Course Outcomes that are listed on the course syllabus. For each, give an assessment of the students’ ability to meet that specific outcome. “Basis for assessment” should be “#xxx” where xxx is the listed homework/project/exam that measures that outcome. Changes to course outcomes and SOs require teaching cluster approval.

---

\(^{12}\) Student self-assessments surveys available on SharePoint.
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<table>
<thead>
<tr>
<th>Course Outcomes</th>
<th>ABET SO's</th>
<th>Basis for Assessment</th>
<th>Average Score (from homework, project, exam etc.)</th>
<th>Comments for teaching cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Understand roles of process safety, environmental protection, and society in the practice of chemical engineering (f).</td>
<td></td>
<td>c,f</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>4. Appreciate the need for over-pressure protection of equipment and understand the related design practices (c).</td>
<td></td>
<td>c</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5. Prepare the preliminary process design to meet defined business, throughput, quality, and safety/environmental specifications (e).</td>
<td></td>
<td>e</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
9.7 Digication e-Portfolio Instructions and Template

Instructions for E-Portfolio Submission

Please contact Tracy Carter at t.carter@northeastern.edu if you have any comments or questions.

Beginning in the Spring of 2018, the Chemical Engineering Department is asking students to create an e-portfolio. Students do not need to begin this process until directed by a course instructor. Once you have been given instructions, you may begin to develop your e-portfolio which will be a place where you can save, reflect, and begin to showcase achievements and skill development. Updated student e-portfolios will need to be submitted to the assignment posted within Digication at the end of every semester.

The Chemical Engineering Department will be using some of this information for the ABET accreditation process. ABET, the Accreditation Board for Engineering and Technology (http://www.abet.org/accreditation/), in order to facilitate ABET program assessment, students will be required to keep a Chemical Engineering e-Portfolio, updated with work throughout their undergraduate program at Northeastern. Anonymous samples of the e-portfolios will be used to document student development on the ABET student outcomes which are required of the Chemical Engineering department to maintain the ABET accreditation. Video instructions are provided below.

To document competencies developed throughout your program:

- Click on the “Digication E-Portfolio” link to the left.
- Click on the green plus icon at the top left of the Digication screen to create your e-Portfolio and include your full name and “Chemical Engineering E-Portfolio.”
- Follow the instructions in the portfolio template to add content.
- You’ll need specific instructions from the instructor of each course so that you know what assignments from their course to upload and into which section of the e-Portfolio.
- You’ll need to publish your portfolio template by clicking on the publish button and then confirm that all the content you’ve uploaded is visible if you click on the “Publish” tab at the top right.
- Each semester, you’ll make two submissions. In order to submit, click on the “Settings” tab at the top right of the screen. Choose “Submit” from the menu.
  - You should submit your entire e-portfolio to the assignment dropsbox with the title that contains both “Complete” and the semester you’re submitting for.
  - You should submit only the pages you’ve updated to the assignment dropsbox with the title that contains “Sections Updated this semester” and the semester you’re submitting for.
- Choose the correct assignment available for you to submit to.
- Click the “portfolio” option.
- Click the home option to submit the entire e-Portfolio to the “Complete” assignment dropsbox. Click the specific pages you’ve updated to submit those updated pages to the “Sections Updated this semester” assignment dropsbox.

Screencast: Creating your Chemical Engineering Portfolio

Creating your Chemical Engineering Portfolio

Welcome to Digication!

My ePortfolios

course

show all my ePortfolios

Created with
Screencastomatic

Try our free recorder
How to Submit E-Portfolio for Grading/Review

When you are ready to submit your portfolio for grading and/or review, follow the steps outlined in this video:

Publishing and Submitting your Chemical Engi...

Welcome to Digication!

My ePortfolios Shared with this course

Alyssa Faria's ePortfolio - 11-17

Created with SCREENCASTOMATIC

Try our free recorder

Tracy Carter

View Sections Add/Edit

Home A. Apply Knowledge B. Experiment: Design, Conduct and Interpret C. Process Design D. Teamwork
E. Problems: Identify, Formulate, and Solve F. Responsibility: Professional and Ethical G. Communication H. Global Impact
I. Lifelong Learning J. Professionalism K. Techniques, Skills and Tools

View Pages Add/Edit

A. Apply Knowledge

CHEM 1131
MATH 1343
PHYS 151/2/3
Physics 1/Lab
CHME2310 Transport 1
CHME2311 Transport Lab 1
Thermodynamics 1
Design
Organization or Club
Co-op
CHME4429

View Text Edit Publish Delete Drag to reorder

The following pages demonstrate an ability to apply knowledge of mathematics, science, and engineering in the general field of chemical engineering.

Note to user: Each page (located on the left) identifies the course or place where the ability was acquired or the objective was met. Add a new page for any new course or place where you want to show evidence. Add a module (located above) to each page to add evidence to demonstrate the ability (objective). Adding more than one module to a page will show more than one piece of evidence within the same course (place) that this ability (objective) was met.

Please include a reflective paragraph to each module to describe how the evidence that you add meets the section objective.
## 9.8 Course Materials

The following materials were generated by the faculty teaching the course in consultation with Tracy Carter to provide supporting safety materials. Lists the sources.

<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
<th>Source Type</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIChE Center for Chemical Process Safety (CCPS)</td>
<td>Introduction to Process Safety for Undergraduates and Engineers (2016)</td>
<td>Book</td>
<td></td>
</tr>
<tr>
<td>American Institute for Chemical Engineers (AIChE)</td>
<td>AIChE Academy Education</td>
<td>On-Line</td>
<td><a href="https://www.aiche.orgacademy">https://www.aiche.orgacademy</a></td>
</tr>
<tr>
<td>Chemical Safety Software</td>
<td>Safety Data Sheet Search</td>
<td>On-Line</td>
<td><a href="https://chemicalsafety.com/sds-search/">https://chemicalsafety.com/sds-search/</a></td>
</tr>
</tbody>
</table>
9.8.1 Conservation Principles

Joshua Gallaway

In Conservations Principles, students were studying the production of ethylene oxide. As a homework problem, they had to conduct mass and energy balances on the system. In addition, the following question was added to get them to explore the safety hazards associated with this process:

You are new to the company that is producing ethylene oxide and you want to educate yourself on the hazards associated with the chemicals you are working with. The safety data sheets (SDS) contain instructions for the safe use of a material, as well as its potential hazards in areas such as health, flammability, and reactivity. (This is also sometimes called a material safety data sheet or MSDS.)

   a) Obtain and reference at least three SDS for each substance used in the process in #2. This can be done via a web search tool such as https://chemicalsafety.com. List the potential hazards for each material as specified by the American Conference of Governmental Industrial Hygienists (ACGIH) and the National Fire Protection Association (NFPA). Are the specifications on each SDS the same or different? If different, why? (This homework problem meets the following course learning outcome: Combine and solve material and energy balances with physical and chemical data to address chemical engineering processes, including evaluating potential safety hazards. (SO c))

   b) There are many acronyms in safety, it is important to take the time to learn what some of the key acronyms mean. What does the ACGIH TLV TWA mean and what is it for each of the chemicals in the process? What is ppm and how do you convert it to mg/L? What does UFL and LFL mean, and what is it for each of the chemicals in the process? What does LD50 and LC 50 mean and what is it for each of the chemicals in the process? Note that some of these values may not be reported in the SDS. If they are not included, just report Not Available for that chemical. (This homework problem meets the following course learning outcome: Express process variables representing pressure, temperature, composition, and flow rates in different unit systems and express the role of dimensionality. (SO a))

9.8.2 Lab 1

Nasim Annabi, Sidi Benchiref, Tracy Carter, and Abigail Koppes

In Lab 1 there are four SACHe outcomes. This is accomplished through two deliverables. The safety checklist and the design project safety analysis.

   Safety Checklist

In Lab 1, students conducted five experiments over the course of the semester. At the beginning and end of each experiment, they must complete a safety checklist. This list requires the students acquire the SDS for each material in the experiment and identify the hazards associated with those chemicals. They also need to identify all the hazards associated with the experiment. The following document must be completed and submitted in the appendix of each proposal and report:

Northeastern University
TO: Transport Laboratory Co-Workers
FROM: Lab Instructor
SUBJECT: Implementing Green Safety into the Design of an Experiment

The following list outlines an early conception of what would make a greener chemical, process, or product.¹

1. Prevention
   It is better to prevent waste than to treat or clean up waste after it has been created.

2. Atom Economy
   Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

3. Less Hazardous Chemical Syntheses
   Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. Designing Safer Chemicals
   Chemical products should be designed to affect their desired function while minimizing their toxicity.

5. Safer Solvents and Auxiliaries
   The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.

6. Design for Energy Efficiency
   Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.

7. Use of Renewable Feedstocks
   A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8. Reduce Derivatives
   Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

9. Catalysis
   Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. Design for Degradation
    Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

11. Real-time analysis for Pollution Prevention
    Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. Inherently Safer Chemistry for Accident Prevention
    Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

TO: Transport Laboratory Co-Workers  
FROM: Lab Instructor  
SUBJECT: Permission to Start Experiment

Please use this checklist to review the safety of your experiment and address any safety hazards before you begin. You may begin once your supervisor signs it:

Emergency Phone Number:

Personal Protective Equipment (Check Yes or mark Not Applicable (N/A)):

- Shirt, Long Pants, Socks, Closed Toed Shoes  ☐Yes  ☐N/A
- Hair Tied Back  ☐Yes  ☐N/A
- Loose Clothing Secured  ☐Yes  ☐N/A
- Safety Glasses  ☐Yes  ☐N/A
- Hard Hat  ☐Yes  ☐N/A
- Gloves (ie. thermal, latex)  ☐Yes, Type:  ☐N/A
- Lab Coat  ☐Yes  ☐N/A
- Ear Plugs  ☐Yes  ☐N/A

Insert Safety Selfie Group Image (Image should capture head to toe PPE):

System Safety:

- Over pressure: Maximum Instrument Pressure:  ☐Atmospheric  ☐Other, Specify:
- Under pressure: Minimum Instrument Pressure:  ☐Atmospheric  ☐Other, Specify:
- System Temperature:
  Steam or Electrical Heat required:  ☐Yes  ☐No
  Maximum System Temperature:

- Vapors Properly Vented  ☐Yes  ☐No  ☐N/A
- Electrical Hazards
  Emergency Shutdown Procedure:
Emergency Shut-Off Switch Number: ☐N/A

Lock/out-Tag/out Procedures: ☐N/A

Electric Shock Mitigation procedures:

- Environmental hazards:
  System Drainage Valves that should be closed during normal operation: ☐N/A

Emergency Containment Procedure:

Equipment Safety:

- Equipment Limitations (Specify each piece of equipment and the material compatibility, temperature, pressure, and operating ranges):

- Visual inspection of apparatus: ☐All materials in working order ☐Items need checking:

Comments:

Materials Safety

- Specify all process chemicals:

- SDS reviewed and present during the experiment (note if SDS missing)
  ☐Reviewed ☐Missing, Specify: ☐N/A for Air or Water Only

- All chemical containers labeled prior to experimentation:
  ☐Yes ☐No ☐N/A

- Process Chemical NFPA Ratings: ☐N/A ☐Yes , if Yes identify:

<table>
<thead>
<tr>
<th>Specify Chemical:</th>
<th>☐N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Health Rating:</td>
<td>☐N/A</td>
</tr>
<tr>
<td>Maximum Flammability Rating:</td>
<td>☐N/A</td>
</tr>
<tr>
<td>Maximum Reactivity Rating:</td>
<td>☐N/A</td>
</tr>
<tr>
<td>Special Information:</td>
<td>☐N/A</td>
</tr>
</tbody>
</table>

- Nonhazardous Liquids (Dilute down drain/ trash):

Identities:
• Hazardous Liquids (Hazardous Waste Container):
  Identities:
  • Nonhazardous Solids (Trash):
    Identities:
    • Solids (Hazardous Waste Container)
      Identities:
      • Solids (Sharps Container)
        Identities:

Date:

Experiment Start Time: Experiment End Time:

Image of Work Area Prior to Experimentation:

INITIALS OF CO-WORKERS:

INITIALS OF SUPERVISOR:
At the end of your experiment, please check that the area is clean and equipment and chemicals are safely stored. Highlight safety issues that were encountered and how they may be mitigated in the future.

Note: (SI) fields indicate a supervisor initials are needed.

**System Safety:**

- Valves Closed
  - □ Yes  □ No
  - □ N/A

- Heating System Power/Steam Off
  - □ Yes  SI  □ No
  - □ N/A

- System Power Off
  - □ Yes  □ No
  - □ N/A

- Systems operating properly
  - □ Yes  □ No
  - □ N/A

  System maintenance recommendations:

  Unusual Fumes/Sounds locations:

**Equipment Safety:**

- Tools safely stored
  - □ Yes  □ No  □ N/A

- Major pieces of equipment operating properly
  - □ Yes  □ No

- Equipment requiring maintenance:

**Material Safety:**

- Chemical Inventory: Spent chemicals scanned out of inventory
  - □ Yes  SI  □ N/A

- Nonhazardous Liquids (Dilute down drain/ trash):

  Identities:

  - Hazardous Liquids: Hazardous Waste Container □ Labeled □ Dated

  Identities:

  - Nonhazardous Solids (Trash):
Identities:

- Hazardous Solids: Hazardous Waste Container ☐Labeled ☐Dated

Identities:

- Sharp Solids (Broken glass and syringe tips): ☐Disposed of in Sharps Container, ☐N/A

- Surfaces and instruments cleaned and/or wiped down:
  
  - ☐ Bench Top
  - ☐ Temperature measuring devices clean and returned to grey cabinet
  - ☐ Pressure measuring devices clean
  - ☐ Scales and balances clean and returned to Room 11
  - ☐ Volume measuring glass/plastic ware labels removed, clean and on the glass drying rack
  - ☐ All other lab ware cleaned and returned, specify:

Image of Work Area after Experimentation:

![Image of Work Area after Experimentation]

Final Wrap-up:

Identify all safety concerns encountered during the experiment with suggested mitigation procedures.

SI, ☐N/A
☐ Safety Glasses, Hard Hat, Lab Coat, Thermal Gloves returned
☐ Markers returned
☐ Extension cords returned
☐ Computers in sleep mode
☐ Submit raw data to Blackboard ☐ N/A
☐ SDS returned to folder ☐ N/A

Date:

SIGNATURE OF CO-WORKERS: ________________________________

SIGNATURE OF SUPERVISOR: ________________________________

SIGNATURE OF INSTRUCTOR: ________________________________
Design Project

In Lab 1, students design their own experiment for a final project. In their experiment proposal, they needed to write a safety analysis justifying the choices of chemical for their experiment and employ methods of inherently safer design, as well as the mitigation and control of hazards. The following is a description of what needs to be in the final design project proposal:

The purpose of this formal proposal is to communicate:

- The design of an experiment based on Fluid Transport that illustrates some of the concept(s) explored thus far.
- Sufficient background to explain the theory behind the concepts of the experiment (i.e. laminar flow requirements, or turbulent mixing control, etc.) and the relevance of the context (i.e. composting, or biofuels, etc.) to chemical engineering.
- An explanation of the predicted results relative to the theory.
- A design of the apparatus, method and engineering flowsheet.
- A well-developed strategy for data collection.
- Thorough safety analysis including personal, material, equipment, and system safety.
- Estimated itemized cost for implementation.
- Estimated timeline for experiment including how long to acquire equipment/supplies, how long to build the apparatus, and how long to run the experiment.
- Project the broader impact of the results of the experiment ($ and/or other).
- Document in the appendices the following:
  - The step-by-step procedures including equipment list, description, safety checklists, and flowsheets.
  - All the raw data tables.
  - Relevant, non-trivial calculations to illustrate the theory and identify how the collected data will illustrate the concepts intended to be demonstrated.
  - Any relevant vendor quotes.

The details of meeting these requirements will vary depending on the approach taken for each challenge. Communication with the Laboratory Instructor will determine the appropriate level of detail necessary to meet each requirement.

9.8.3 Professional Issues

Julie Nguyen, Sarah Kostanski, and Jacob Walker

In Professional Issues, the students give a presentation on a safety incident to demonstrate their understanding of important incidents that define process safety, and how these incidents affected the practice of chemical engineering. The following is a list of project choices and the specifications of the presentation to meet the course outcomes:
To Engineer is Human:  
Do we learn anything from our historical mistakes?

| Combustible Dust Explosion: AL Solutions Fatal Dust Explosion (2010) (see csb.org) | Oil Spills BP Oil Spill (2010) |

Other potential topics:  
Bee Colony Collapse  
GMO Foods – What is all the controversy about? (1994 – now)  
Risks and Benefits of:  
Fracking  
Nuclear Power

Presentations should include:

- The facts of the case (what is the issue?)
- Parties involved- companies, communities, customers/clients?
- Identify regulations that were applicable/who were the regulators?
- Who was impacted by this case?
- How was the issue resolved or how was it left?
- What preventative measures could have been taken?
- Has a similar event happened in the past?
9.8.4 Transport 2
Lucas Landherr
In Transport 2, students were introduced to the process of hazard evaluation and risk assessment and assessed using the following homework problem:

“Consider both a) a heat exchanger like we have previously discussed, and b) a separations equipment device that you have some familiarity with, like a distillation column, liquid-liquid extraction device, reverse osmosis membrane, a gas stripper, or other device that you may know from research or co-op. For each of these devices, consider hazard evaluation and risk assessment and address the following questions:

i) What could go wrong in the process?
ii) How significant could the consequences be?
iii) How likely is it to occur?

Additionally, you may find it helpful to complete the SACHe Certificate Program – Minimizing and Identifying Process Safety (https://www.aiche.org/academy/courses/ela952/sacher-certificate-program-identifying-minimizing-process-safety-hazards) which is free to all undergraduate student AIChE members (and registering for student AIChE membership is free).”

9.8.5 Kinetics
Thomas Kinney
In Kinetics, students studied the T2 incident which is covered in the course textbook by Scott Fogler, “Elements of Chemical Reaction Engineering”. Students watched the CSB video on the T2 incident and had an in-class discussion on the incident. Using Python, they ran simulations turning reactions on and off to study the results. Then their knowledge was assessed with the following quiz:
**QUESTION 1**
Overall were the chemicals involved in the T2 process
- Toxic
- Flammable
- Reactive
- All of the above

**QUESTION 2**
The runaway condition itself was due to the materials' properties
- Toxicity
- Flammability
- Reactivity
- All of the above

**QUESTION 3**
The T2 system design would have been inherently much safer if
- there was backup/redundancy in the cooling water supply
- there was a pressure relief system
- there were temperature sensors
- the vessel was a pressure vessel
In Process Control, students were introduced to the hazard identification procedure called Layers of Protection Analysis (LOPA). They were given the following project including the specified safety expectations to demonstrate their ability:

“Assignment Overview: Based on one of the project descriptions provided, groups of 4-5 individuals will design a control system using the information that you have learned in the Process Control course. Through research, knowledge, and familiarization with the system and theory involved in its operation, you will incorporate a process control schematic, develop transfer functions, and perform simulations of the process. You will also detail safety control measures into your design.
You must write a report that will account for 17% of the final course grade. The safety section should include:

Safety:
- Here you will outline all of the valves you have in your process flow diagram
- Identify if they are Fail Open or Fail Close and why
- Identify any pressure relief valves and other safety measures you have taken
- For the specific scheme you are controlling in the problem formulation section of this report, please identify all safety hardware that will need to be included in the design.”

9.8.7 Capstone 1

Francisco Hung

In Capstone 1, students completed a project where they had to demonstrate their familiarity with the major regulations that impact the safety of chemical plants. The projects they had to choose from were taken from the Appendix of Towler, G.; Sinnott, R. Chemical Engineering Design, 2nd Edition, Butterworth-Heinemann, 2013; http://booksite.elsevier.com/9780080966595/index.php.

- “Ethylhexanol from Propylene and Synthesis Gas: Design a plant to produce 40,000 metric tons/year of 2-ethylhexanol from propylene and synthesis gas, assuming an operating period of 8,000 hours on stream.
- Chlorobenzenes from Benzene and Chlorine: Design a plant to produce 20,000 metric tons/year of monochlorobenzene together with not less than 2,000 metric tons/year of dichlorobenzene, by the direct chlorination of benzene.
- Methyl Ethyl Ketone from Butyl Alcohol: Design a plant to produce 10,000,000 kg/year of methyl ethyl ketone.
- Acrylonitrile from Propylene and Ammonia: Design a plant to produce 100,000,000 kg/year of acrylonitrile from propylene and ammonia by the ammoxidation process.
- Urea from Ammonia and Carbon Dioxide: A plant is to be designed for the production of 300,000 kg per day of urea by the reaction of ammonia and carbon dioxide at elevated temperature and pressure, using a total-recycle process in which the mixture leaving the reactor is stripped by the carbon dioxide feed.
- Hydrogen from Fuel Oil: A plant is to be designed to produce 20 million standard cubic feet per day of hydrogen of at least 95% purity. The process to be employed is the partial oxidation of oil feedstock.
- Chlorine Recovery from Hydrogen Chloride: A plant is to be designed for the production of 10,000 metric tons per year of chlorine by the catalytic oxidation of HCL gas.
- Analine from Nitrobenzene: Design a plat to make 20,000 metric tons per year of refined aniline by the hydrogenation of nitrobenzene. The total of on-stream time plus regeneration periods will be 7,500 hours per year.”

In presentation 1 the students must:
1. Design team: introduce your group members: education (your high school), co-op experience, etc.
2. Objectives: why is your product important? Restate the design problem; briefly review the patent(s) / associated document(s) to help the audience understand the technology; discuss the problem that you are planning to solve.
3. Block flow diagram: provide a block flow diagram of the process with key raw materials, waste and products clearly identified. You don't need to show a PFD at this point. What thermodynamic model would you choose for your Aspen Plus simulation?
4. Feedstocks: discuss your raw material requirements: describe available feedstocks, grades, quality issues, etc.
5. Product grades: give product specifications, usually as tables or reference to ASTM or USP specifications.
6. OSHA 1910.119 and Materials Safety Data Sheets (MSDS): does your process need to comply with OSHA 1910.119? For the main chemicals in your process, summarize major hazards and health effects, as well as known incompatible materials.
7. Production scale: whatever you think is appropriate; however, ‘economy of scale’ considerations typically motivate companies to develop large projects, allowing them to price their products more competitively, and recover investments faster.
8. Key challenges: list your key challenges to achieving a process simulation of your full design by the end of the semester.

In the draft and final paper, they are expected to:

Technical Proposal
1. Executive summary
   1.1. Project objectives and proposed technology (state design problem, briefly describe the process including block flow diagram)
   1.2. Benefits and advantages (summarize key advantages relative to competing technologies)
   1.3. Main findings and conclusions from your technical and economic evaluation
2. Proposal basis
   2.1. Feedstocks (describe available feedstocks, grades, quality issues)
   2.2. Product grades (give product specifications, usually as tables or reference to ASTM specifications)
   2.3. Processing options (describe process alternatives considered and evaluated)
3. Proposed technology
   3.1. Process description, including relevant process flow diagrams
   3.2. Does your process need to comply with OSHA 1910.119 regulations? Why?
   3.3. Key equipment recommendations: describe any critical reactors and/or unit operations, and explain what was selected and how it was designed, key specifications, and if any special considerations are required based on safety issues (e.g., Materials Safety Data Sheets, MSDS)
   3.4. Process simulation: describe your Aspen Plus simulation, i.e., how you modeled your process and which property model was selected and why. Include a thorough discussions of key simplifications and limitations of your simulation model. Show and discuss flow rates and compositions of raw materials, products and waste streams. Also discuss any unresolved issue in your simulation (e.g., non-converged recycle streams or columns, etc.)
4. Technical and economic assessment
   4.1. Estimate of capital costs: use Aspen Process Economic Analyzer as much as possible; follow guidelines from Section 7.6.4 of your book.
   4.2. Estimate of production costs: provide estimates of variable costs of production (raw materials, utilities, consumables, effluent disposal; see Sections 8.2.1 and 8.4 of your book; please provide references for any pricing data you used) and fixed costs of production (operating labor, supervision, salary overhead, maintenance, etc.; see Sections 8.2.2 and 8.5 of your book). Use Aspen Process Economic Analyzer as much as possible.
   4.3. Estimate of revenues, margins and profits: see Sections 8.2.3, 8.2.4, 8.3 and 8.6 of your book. Use Aspen Process Economic Analyzer as much as possible.
4.4. Economic evaluation: net present value (NPV), and discounted cash-flow rate of return (DCF ROR, also known as internal rate of return, or IRR). See Sections 9.6 and 9.4 of your book.

5. Conclusions: summarize your main findings and conclusions from your technical and economic evaluation.

6. References cited / Bibliography
Supplementary Information / Appendix
   1. Stream tables (from your Aspen Plus simulation). Do not list all stream properties; it is enough to list temperature, pressure, phase, flowrates and compositions.
   2. Links to Materials Safety Data Sheets (MSDS)

9.8.8 Capstone 2

Amit Roy and Thomas Webster
In Capstone 2, the students complete a design project. This project “requires each student to solve a comprehensive chemical process design problem. Topics include heat and power integration in chemical processing, design and scheduling of batch processes, sequencing separation operations, and safety considerations in process design.” In this project, they must characterize the hazards associated with chemicals and other agents and they must demonstrate their understanding of the consequences of chemical plant incidents due to acute and chronic chemical releases and exposures. These skills were demonstrated with the following deliverables:

• “Each group completes one comprehensive project.
• Groups are composed of three or four persons.
• There are oral presentations for each of the following phases*:
  - Project Proposal/Business Case
  - Preliminary Business Plan with Base Case Design
  - Detailed Design
  - Final Design
• There are written reports for each of the following phases:
  - Project Proposal/Business Case
  - Preliminary Business Plan with Base Case Design
  - Detailed Design
  - Final Design
Check List of Report Sections and Order of Appearance (Summary: no more than one page; other sections: no limit):

A. Letter of Transmittal
   1. Title Page
   2. Table of Contents
      List of Figures
      List of Tables
   3. Executive Summary (w/ specific reference to design specifications)
   4. Introduction
   5. Summary
   6. Discussion
   7. Conclusions
   8. Recommendations
   9. Project Premises
   10. Heat and Material Balances
   11. Main Unit Process Flow Diagram
   12. Overall Process Flow Diagram with heat integration and stream flows & compositions between all units in plant
   13. Safety, Health, and Environmental Considerations
   14. Equipment Information Summary – with enough design information to cost equipment
   15. Unit Control and Instrumentation Description
   16. Economics - In addition to DCF (discounted cash flow) analysis, include a summary of operating costs, utility requirements and energy efficiency
   17. Engineering Calculations, Computer Simulation Outputs
   18. References
   19. Acknowledgements
Identifying Current Outcomes and Addressing the Need for Process Safety Education in Unit Operations Courses

June 27, 2018

Tracy Carter (Northeastern University)
Dr. Samira Azarin (University of Minnesota-Twin Cities)
Dr. Janie Brennan (Washington University)
Dr. Elizabeth Hill
Dr. Amy Karlsson (University of Maryland)

Figure 1: Achievement of SACHE (www.sache.org) learning outcomes across the five participating institutions, as rated by participants on a Likert scale (1 = extremely well, 5 = not well at all). Results presented as mean ± standard error of the mean.
Next Steps

1. Continue to build a network of lab instructors to support each other in improving safety education.

2. Survey:
   1. Add elements to survey regarding course characteristics to more clearly identify similarities and differences between programs
   2. Survey a wider population of universities

3. Teaching:
   1. Develop resources for teaching regulations
   2. Develop reflections for safety learning
   3. Measure student safety learning

Questions, Comments, Suggestions?

![QR Code]
Work Process / SOP

For

ABET Continuous Improvement

Revision 1

June 15, 2018
Development of a Standard Operating Procedure for ABET Continuous Improvement.

This document was initiated by Richard Giberti in April 2018. It was reviewed and modified the Gordon candidate and Ronald J. Willey, Vice Chair of the Department of Chemical Engineering, in June 2018. It is presented here as part of this thesis as it includes details of how to incorporate process safety into the curriculum as well as the written procedures to keep the process sustaining as education goals and personnel change with time.

(Electronic copy in SharePoint Undergraduate Education / Course Repository/ABET Work Process saved in this link (accessed 6/29/2018) [link to document])

General course assessment materials description and deadlines

Referenced documents must be posted in the following “Undergraduate Education / Course Repository” folders on SharePoint [link accessed 6/29/2018]

- Syllabi and iAssess forms and Pre- and Post-Assessment Surveys in the:
  - Course Repository folder by:
    - By Course
    - By Semester / Year
- UEC Minutes in the:
  - “Minutes UEC” folder
- Cluster Team Minutes in the:
  - “Teaching Cluster” folder

The following information is to support Instructors with collection and preparation of ABET Continuous Improvement documentation. It is available in the “Undergraduate Education / Course Repository”

- iAssess forms by Course
- ABET 2-Pagers
- Pre-Assessment Surveys by Course
- Post-Assessment Surveys by Course
ABET Continuous Improvement Responsibilities of the Department Administrative Assistant

- Three (3) weeks prior to the start of each semester the Department Administrative Assistant adds a semester folder to the Sharepoint “Course Directory” for each course being taught that semester.
ABET Continuous Improvement Responsibilities of the Department Vice Chair

- One month prior to the start of each semester the Departmental Vice-Chair will send an e-mail containing this Work Process / SOP to ALL Instructors, UEC Member, and Cluster Team members.
- At least one month before the start of the semester the Department Vice Chair will provide the Department Administrative Assistant and the IAB Accreditation Committee Chair with the list of courses and the names of instructors for each section being taught for the coming semester.
- The Department Vice-Chair will train any new Instructor in completion of the iAssess form and where and how to post it and their syllabus on SharePoint.
- At the bi-annual Faculty Education Retreat in May, the Departmental Vice-Chair will assign and notify UEC and Cluster Team chairs and members of their assignment.
- The Departmental Vice-Chair will monitor any changes in the ABET compliance program. They will make the necessary changes in department documents and procedures and inform the IAB Accreditation Committee Chair of the ABET Compliance program changes.
- The Departmental Vice-Chair will forward copies of the Annual Senior Benchmark Survey and the Alumni Survey to the UEC and Team Cluster Members for review and action as appropriate by the end of the Fall semester for discussion at the December Faculty Education Retreat.
- The Departmental Vice-Chair will forward copies of Town Hall minutes and IAB Meeting Student Feedback minutes to the UEC and Team Cluster Members for review and action as appropriate by the bi-annual Faculty Education Retreats in December and May.
ABET Continuous Improvement Responsibilities of the Departmental Chair

- The **Departmental Chair** works with the faculty to document their education roles, goals and responsibilities in the annual merit review. This includes the completion and submission of syllabus, iAssess, and Pre- and Post Assessment Surveys and identifies which teaching cluster they are associated with.

- The **Departmental Chair** takes action as they deem appropriate with regard to delinquent syllabus postings on SharePoint.

- The **Departmental Chair** takes action as they deem appropriate with regard to delinquent iAssess postings on SharePoint.

- The **Departmental Chair** takes action as they deem appropriate with regard to delinquent Pre- and Post-Assessment Survey postings on SharePoint.

- The **Departmental Chair** forwards copies of the Annual Senior Benchmark Survey and Alumni Survey to the Departmental Vice-Chair and the IAB ABET Committee Chair upon receipt from the COE for review at the December Faculty Education Retreat.

- The **Departmental Chair** forwards copies of Town Hall Meeting minutes to the Department Vice-Chair and the IAB ABET Committee Chair for review at the bi-annual Faculty Education Retreats in December and May.
ABET Continuous Improvement Responsibilities of the IAB ABET Committee Chair

- The IAB Accreditation Committee Chair will monitor work process/SOP activities as appropriate to assure the ABET accreditation documentation will be in place for the next audit.

- No later than 2 weeks after the start of the semester the IAB ABET Committee Chair will review the SharePoint “Course Directory” to check that all courses and sections being taught that semester have a syllabus posted.

- The IAB ABET Committee Chair immediately notifies any Instructor delinquent in their submission of their syllabus.

- No later than 3 weeks after the start of the semester the IAB ABET Committee Chair emails a reminder to any Instructor still outstanding with their syllabus posting.

- No later than 4 weeks after the start of the semester the IAB ABET Committee Chair rechecks SharePoint and sends an email to the Department Chair and the Department Vice Chair with the names of all instructors still delinquent with their syllabus posting.

- At the beginning of the Spring semester, ca. January 8th, the IAB Accreditation Committee Chair will remind Chemical Engineering COE Academic Advisor and whomever is the current Capstone II Instructor to coordinate on administering the Senior Benchmark Survey to maximize student participation. Students must be reminded to select programs similar to chemical engineering or biochemical engineering, and not the category listed as chemical engineering technology. Suggest requiring attendance at the class where the survey is administered, and requiring completion of the survey before anyone can leave. Also attempt to administer to Fall semester students.

- No later than 2 weeks after the end of the semester the IAB ABET Committee Chair will review the SharePoint “Course Directory” to check that all courses and sections being taught that semester have an iAssess form posted.

- The IAB ABET Committee Chair immediately sends a reminder to any Instructor delinquent in their submission of their iAssess form.
• No later than 3 weeks after the end of the semester the IAB ABET Committee Chair sends a reminder to any Instructor still outstanding with their iAssess posting.

• No later than 4 weeks after the start of the semester the IAB ABET Committee Chair rechecks SharePoint and sends an email to the Department Chair and the Department Vice Chair with the names of all instructors still delinquent with their iAssess submission.

• The IAB Accreditation Committee Chair will assure that the department PEO’s and SO’s are annually reviewed, and suggest updates if necessary. Normally this is done at the November IAB meeting and documented in the minutes.

• The IAB Accreditation Committee Chair will forward copies of the IAB Meeting Student Feedback minutes to the Department Vice-Chair.
ABET Continuous Improvement Responsibilities of the UEC and Cluster Team Members

Undergraduate Education Committee (UEC)

- The **UEC** will meet regularly to perform the following tasks:
  - Review student petitions
  - Check in on current semester flow of the courses
  - At the beginning of each semester, the UEC shall develop a written list of “charges” for each cluster group initiated for that semester
  - Develop motions for curriculum improvement and then move them forward to the chemical engineering faculty for improvement during the bi-annual Faculty Education Retreats in December and May.
  - Keep faculty informed about undergraduate initiatives occurring at the college and university levels
  - Review teaching assistant assignments 6 weeks before the beginning of the semester

- The **UEC** will maintain a set of minutes of its meetings and post them in the “Undergraduate Education” file in the “Minutes UEC” on SharePoint.

- The **UEC** will in conjunction with the appropriate **Cluster Team(s)** review the Annual Student Benchmark Survey and Alumni Survey and take corrective action and make improvements as appropriate by the December Faculty Education Retreat.

- The **UEC** will in conjunction with the appropriate **Cluster Team(s)** review the Town Hall Meeting Feedback and IAB Meeting Student Feedback minutes and take corrective action and make improvements as appropriate by the December and May Faculty Education Retreat.

Cluster Teams

- The **Cluster Teams** will be formed based on the curriculum improvement motions identified by the **UEC**.
- The **Cluster Teams** will review the iAssess forms and give feedback to the instructors in the courses assigned to the cluster as appropriate during the Fall and Spring Education Retreats.
- The **Cluster Teams** will update course outcomes to reflect the goals of the Cluster Team during the Fall Education Retreat.
- The **Cluster Team** will prepare a report of the clusters actions that semester and posts it in the “Cluster Team” folder in the “Course Repository” on SharePoint at the end of the Fall and Spring Education Retreats.
Every 3 Years (2017, 2020, 2023, etc.) UEC / Cluster Teams will

- Check that CHME “course descriptions” in the Northeastern On-Line Catalog match course descriptions in the respective course syllabus
- Review and update ABET 2-Pagers as appropriate
- Confirm that “course outcomes” in each current syllabus are those in the ABET 2-Pagers
- Check that the prerequisites are mapped properly
- Check mapping of “course outcomes” to “ABET Student Outcomes”
- Other tasks to be identified by the Departmental Vice-Chair
ABET Continuous Improvement Responsibilities of the Instructors

- At least 2 weeks before the start of the semester all Instructors will review the iAssess forms from the previous time their course was taught and incorporate recommended improvements in their current syllabus as appropriate.

- No later than 1 week before the start of the semester each Instructor posts the syllabus for their course on SharePoint.

- On the first day of class each Instructor will administer the Pre-Assessment Questionnaire to all students in their class.

- Before the end of each semester each Instructor will administer the Post-Assessment Questionnaire to all students in their class.

- No later than 2 weeks after the end of the semester each Instructor will complete and post the iAssess form for their course on SharePoint.

- The Fall Semester Capstone II Instructor will administer a survey containing the Senior Benchmark Survey feedback questions to the Capstone II class.

- The Spring Semester Capstone II Instructor will administer the Senior Benchmark Survey during a class in which ALL students must participate. The Instructor will also inform the participating students which major they should report under.

- At the end of each semester Instructors are encouraged to post their course notes in the "Course Materials from Previous Instructors" folder for that course in the Course Repository.

- Each Instructor will work with a Cluster Team to implement new course outcomes as part of the continuous improvement process.
ABET Continuous Improvement Responsibilities of the Department Business Manager

- The Department Business Manager will train any new Instructor with how to access and use SharePoint.