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Sharing Best Practice in Safety Between Engineering Disciplines

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Professional Skills and Safety are my main pedagogical interests. I use the Chemical Engineering laboratory to implement safety training to improve safety culture, and to adapt assessment methods to enhance development of students' professional skills. I am an Assistant Professor of Chemical Engineering at the University of Virginia and I hold a B.Sc. (University of Saskatchewan) and Ph.D. in Chemical Engineering (Queen's University). Complimenting my pedagogical research is an interest in bioprocess engineering, environmental engineering, environmental risk management, and I have authored >40 peer reviewed publications in these fields. I'm also active in developing workforce development initiatives, specifically within the biopharmaceutical manufacturing space. Beyond academia, I have 7+ years of international consulting experience working with the U.K. government, European Union, and the United Nations.

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Sharing Best Practice in Safety Between Engineering Disciplines

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Abstract

Engineering Laboratory courses are used to teach many of the core professional development competencies that are required of engineering graduates. Safety is one competency that is highly valued by industries (e.g. petrochemicals, pharmaceuticals, aeronautical) that hire from a variety of engineering disciplines, but is not commonly taught across the disciplines. In this paper, we discuss a work in progress to transfer safety pedagogy from a Chemical Engineering undergraduate laboratory to a Mechanical Engineering undergraduate laboratory. First, we present results from a baseline safety culture survey that highlights commonalities in student perceptions about safety between the disciplines. Second, we will discuss the challenges and benefits of sharing pedagogy between the disciplines. Finally, we will comment on the integration of professional development training within the engineering laboratory and how it ensures that students practice expected professional behavior rather than simply *learn about* professional standards.

Keywords

Process safety, laboratory pedagogies, professional skills, interdisciplinary transfer

Introduction

Safety education is a core professional development competency that serves the dual purpose of keeping students safe in the engineering laboratory and preparing them for careers in industries that highly value safety (e.g. petrochemicals, pharmaceuticals, aeronautical). In the lab, students receive training to ensure the safe operation of equipment, appropriate use of personal protective equipment (PPE), and the correct method for managing hazards. Though accidents in research and teaching laboratories are rare, they do occur and recent research suggests that safety procedures in academic labs lag behind the standards set by industry.[1] The American Chemical Society and the American Institute of Chemical Engineers have called for improvements to be made to the safety cultures of academic institutions.[2] Changes to safety cultures require safety education, focused effort, and repetition. In practice, this means replacing single instances of safety training (e.g. seminar) prior to the start of a laboratory course with a series of safety initiatives that require students to engage with safety on multiple occasions.

Chemical Engineering (CHE) is one of the few disciplines that teach specific courses or modules on process safety. A major driver of this requirement is the Accreditation Board for Engineering Technology (ABET), which stipulates that students must receive process safety education that includes the identification of hazards associated with the design, analysis, and control of engineering application of chemistry/physics/biology.[3]

Safety education supplements laboratory safety training by providing students with knowledge about hazard identification, risk assessment, and risk management. Safety behaviors more in-line with industry expectations can begin to form when these concepts are integrated into the laboratory experience, stressing the importance of safety thinking each time students enter the laboratory. In previous work we implemented a series of safety education interventions into a 4th year CHE lab course and demonstrated a statistically significant improvement in students' perceptions about safety.[4] As student perceptions shifted, so too did the safety culture in the laboratory. By providing multiple opportunities for students to practice discussing and engaging with safety in the laboratory, we were able to improve the students' professional safety skills.

Building on the success of this study, this project explores opportunities to transfer the pedagogy to another program, Mechanical Engineering (MechE), with similar laboratory activities and outcomes. Professionally, approximately 50% of the CHE and MechE student body are employed in the manufacturing sector[5]. Though Chemical Engineers tend to work in chemical and pharmaceutical manufacturing, and Mechanical Engineers work in machinery and engine, turbine, and power manufacturing, all manufacturing industries prioritize process safety skills. The laboratory experience is also common to both CHE and MechE programs. Both laboratory sequences expose students to a variety of hazards that require safety training and careful management, though ABET does not explicitly require the MechE curriculum include process safety education. Table 1 summarizes the similarities shared between the two disciplines at the University of Virginia (UVA).

We believe that process safety, as a professional skill, is transferrable between engineering disciplines. In this paper we begin the work by conducting a baseline safety culture survey that provides information about commonalities in student perceptions about safety between the disciplines. Information from this survey will identify opportunities to adapt methods used in CHE that are appropriate safety education interventions for the MechE laboratory. Second, we will discuss the challenges and benefits of sharing pedagogy between the disciplines, highlighting our efforts to contextualize content within the disciplines. Finally, we will present plans to transfer successful interventions from the CHE laboratories to MechE.

Table 1. Comparison of CHE and MechE Laboratory Structures

CHE	**Structure**	**MechE**
Two: • CHE Lab I (Spring 3rd Year) • CHE Lab II (Fall 4th Year)	*Multiple laboratory courses in sequence*	Three: • Mechanics Lab (2nd year) • Thermofluids lab (Fall, 3rd year) • MechE Lab (Spring, 3rd year)
• Steam (high temperature) • Chemical (acid/base/toxicity) • Rotational elements • High pressure (water/gas cylinders) • Reactivity (hydrogen gas) • Potential for splash • Broken glassware	*Common hazards associated with experiments*	• Large machinery • Pinch points • High temperature • Electricity (low V) • High pressure (water/gas) • Rotational elements • Chemical (glycerin, engine oil) • Noise
• Students review the departmental safety manual and complete safety quiz before entry. • Hazards are discussed with TAs and recorded in lab reports	*Method of safety training (pre-intervention)*	• Students review safety issues in the laboratory manual and discuss hazards with TAs • TAs supervise equipment use
• Students are advised to refresh their review of the safety manual	*How is safety training refreshed throughout the sequence*	• Discuss safety as part of experimental plan
• Hazards and safety issues are discussed in planning presentation and recorded in lab reports	*How do students share safety comprehension*	• Not currently done. • Opportunity for improvement.

Safety Perception Survey

Safety culture is the concept of reflecting on the actions, attitudes, and behaviors of laboratory members concerning safety.[6,7] Safety perception surveys can be used to assess an individual's actions, attitudes, and behaviors about safety, and the results can be analyzed using a safety culture framework. An example framework proposes five levels of safety culture maturity.[7]

1. Pathological – It does not matter what we do, as long as we do not get caught.
2. Reactive – We react with a safety drive after things go wrong, and then we stop.
3. Calculative – We have systems that can manage all hazards.
4. Proactive – We continue to work on problems that we identify.

5. Generative – We look for new areas of risk and we do not take past success as a guarantee against future failure.

We expect that the behavior students exhibit when they first engage with the laboratory will be reactive and calculative. Students will listen to the safety training and do their best to follow procedures. As the students build their safety knowledge, and thus their safety skills, we expect to see evidence of proactive and even generative behaviors. We began our work by conducting a baseline assessment of safety culture in both CHE and MechE labs and we used this information to identify opportunities for pedagogy transfer.

Methods

Perceptions can also provide insight about the effectiveness of safety instruction and its reinforcement by instructors and teaching assistants. A baseline assessment of safety perceptions was adopted from an earlier work.[4] The pre-course safety survey was given to 3rd year CHE students beginning their first CHE lab course, 4th year CHE students beginning their second CHE lab course and 3rd year Mech students beginning the second lab course in the sequence. All students would have some lab experience, received some safety training, but had not received safety education interventions aimed at improving safety culture. The survey measured student attitudes about an individual's safety compliance, their tendency to be proactive, and their willingness to engage with faculty and colleagues to promote safe behavior. The survey was administered online using Qualtrics and comprised eleven questions (see Table 2). Students recorded their responses using a Likert scale with ratings that ranged from Strongly Agree (1), Agree (2), Somewhat agree, (3), Somewhat disagree (4), Disagree (5), Strongly Disagree (6).

Results and Discussion

The survey was used to compare differences in perception between Chemical and Mechanical Engineering students regarding safety in the laboratory. Data from this survey will serve as a baseline for assessing the effect that future pedagogical interventions have on the safety culture. Results also indicate the types of interventions that are likely to be most effective.

Results are presented in Table 2. An average score of approximately 1 suggests that students were in strong agreement with the statement. Average scores of 2 and 3 indicate declining agreement with the question. We categorize responses that received scores of two and greater as opportunities for safety education interventions.

Table 2. Average results from safety perception survey. Scores are on a 6-point Likert scale with 1 being “Strongly Agree” and 6 being “Strongly Disagree.”

Theme	Questions	CHE (n = 65)	MAE (n = 131)
Evidence of individual compliance	Expectations regarding personal and lab safety are clear	1.55	1.46
	I have a good understanding of the safety requirements (such as use of PPE)	1.57	1.64
	I believe I received adequate safety training to assure a safe work environment in the UG lab	1.63	1.63
	I am provided the appropriate personal protective equipment to complete	1.53	1.51
Evidence of safety engagement	I feel comfortable asking for help or oversight from Faculty and TAs when planning my work or setting up new experiments	1.43	1.47
	When I observe a potential safety issue, I feel comfortable raising or reporting safety issues to Faculty and TAs	1.66	1.62
	I feel comfortable intervening with a colleague to prevent an unsafe behavior from occurring	1.75	1.74
Evidence of proactivity	**My Lab Group regularly discusses safety issues**	**1.97**	**2.83**
	My Lab Group regularly discusses near misses	**2.64**	**3.31**
	My Lab Group regularly discusses areas for improvement	**2.08**	**3.31**
	My Lab Group consistently adheres to the stated safety policies and practices established in the Safety Manual	1.53	1.59

Overall, both groups report overwhelming agreement that they have been provided adequate training, that expectations about safety have been made clear, and that they have good understating of safety requirements. These results suggest that both programs have well established safety training procedures and that students understand the expectations regarding safety and safe behavior in the laboratory.

We also observe that both groups report overwhelming agreement that they feel comfortable discussing issues or concerns about safety in the laboratory. We design our laboratories to be spaces where students can explore and fail (experimentally) without judgment. From a safety perspective, open communication is vital for transferring information about hazards and risk. We spend considerable time and effort to foster these types of productive and meaningful environments and the results suggest that we have been successful.

We begin to observe differences in responses between the groups when we asked questions about proactivity. We would expect that groups that exhibit stronger safety cultures would perceive themselves as more opening discussing safety and near misses with their teams. This would demonstrate an awareness that safety is as much an issue of keeping colleagues safe (because of individual behaviors) as it is to keep the individual safe. In general, we see that CHE students perceive themselves as participating in more discussions about lab safety as a group, as well as participating in discussions that might lead to improvements in safety compared to the MechE students. Both groups of students received basic safety training prior to completing this survey. The CHE students would not yet have received process safety education as part of their capstone design sequence so we surmise that they might have been exposed to safety discussions interspersed elsewhere in the curriculum, e.g. discussion about reactive hazards in reaction engineering course.

Conclusion

Our preliminary findings suggest that perceptions about safety in the laboratory differ between CHE and MechE students. Our next steps are to understand why these differences might exist between groups and to develop safety education interventions specific to MechE laboratory applications, e.g., safety moments, safety assignments, and incident and near miss reporting. We expect to uncover unique challenges associated with the transfer of pedagogy between disciplines. For example, differences in class sizes, time commitment (in lab), assessment structure, student expectations, and TA training (e.g. modelling good behavior) that will require careful consideration to ensure seamless transfer of methods.

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I am an Associate Professor of Mechanical and Aerospace Engineering at the University of Virginia where I am the Director of Undergraduate Experimental Labs. I earned a B.S. in Ocean Engineering from the US Naval Academy and M.S. and PhD in Civil Engineering from Vanderbilt. Prior to pursing a career in academic, I was a Navy Civil Engineer, an experience which informed my pedagogical interest in developing professional skills in students.