Board 5: Collaborative Research: Experiential Process Safety Training for Chemical Engineers

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Introduction:

Engineering solutions typically involve weighing multiple competing and often conflicting variables in an attempt to come to an optimal solution. Since many engineered systems are used by or impact employees, customers, and the public, the safety and wellbeing of those people must factor heavily into engineers' decision making processes. Indeed, in the professional codes of numerous engineering societies, the safety, health and welfare of the public is at or near the top of the list in important and fundamental tenets of the profession [1-4].

Given the importance of process safety in engineering, the American Institute for Chemical Engineers (AIChE), the Chemical Safety and Hazard Investigation Board (CSB), and the engineering accrediting agency (ABET) have provided guidelines specifically for chemical engineering programs that require them to include explicit instruction in process safety and hazard identification. Since 2011, the accreditation criteria for chemical engineering programs has included language that addresses the study of process safety and hazards as a core element of a chemical engineer's education [5].

Within these guidelines, however, how individual chemical engineering programs teach process safety varies widely. An excellent and recent review of Process Safety Education is provided by Mkpat, Reniers, & Cozzani [6], who identify two primary education vectors for process safety instruction: integration with existing coursework or the development of standalone process safety classes. Both of these methods have pros and cons, and there has been a significant development of educational tools, including safety-focused problem sets [7] and safety-focused modules [8] for classroom integration.

Despite these improvements, a recent AIChE/NSF report notes that much of process safety education is still largely outsourced to industry [9]. The report also notes that while process safety education *content* may be there, the "safety culture" education, i.e., factors that go into how process safety decisions are made, is still lacking. Indeed, industrial participants in the AIChE/NSF study stated their significant concern about the lack of "safety culture" apparent in new chemical engineering graduates who lacked prior work experience, and specifically stated that students lacked exposure to relevant codes and standards, such as EPA and OSHA regulations. As one senior industrial practitioner put it, "*There are way too many chemical engineers in industry that...do not understand the long-term consequences of their actions, and try to find a way around them because of either 'time' or 'costs'*" [9].

This quote reinforces that it is not always the technical content of process safety education that is in question, but rather the lack of situational awareness in which students must make process safety decisions, and how those decisions are influenced by external, non-technical elements, such as productivity or economic constraints. This was reiterated by Pitt [10], who noted that "...universities are good at teaching specific but isolated topics, but less good at getting students to put them together, in part due to the fact that most academics are themselves narrow specialists, often with no experience of industry."

Assessment of how students think about process safety more broadly is challenging. One reason may be that the content is most often taught in a senior level course, such as design, and is being assessed mostly for technical competence and as one of several other criteria under evaluation [11]. The lack of validated assessment methods for process safety thinking, coupled with the general lack of authentic situations in which students can make these decisions presents us with an opportunity to address both points. In this paper, we will discuss both the creation of a virtual process safety environment which attempts to address the authenticity issue, as well as the development of an assessment tool, the Engineering Process Safety Reasoning Instrument (EPSRI), which is based on previous work in assessing students' moral and ethical reasoning in an engineering context.

Project Objectives

This work aims to answer the following three research questions:

1. Is there a relationship between the use of a virtual decision making environment and changes in students' process safety decision making skills?
2. Does a process safety virtual environment increase students' motivation to learn about process safety?
3. Are there any demographic differences that exist in students' process safety decision making skills and students' motivation to learn with the use of the virtual environment?

Answering these questions is challenging using assessment tools available in the literature since to the authors' knowledge there are no instruments which measure a student's process safety decision making skills. With this in mind, the first step in this work was to develop, test and attempt to validate a suitable process safety assessment instrument. One existing instrument, the Defining Issues Test Version 2 (DIT2) has been developed to evaluate a person's ethical decision making in a neo-Kohlbergian ethical context [12]. The style and structure of the DIT2 has since been adapted by engineering educators to develop instruments specific to ethical decision-making in engineering contexts, such as the Engineering Ethical Reasoning Instrument (EERI) [13] and the Engineering and Science Issues Test (ESIT) [14]. While the DIT2 and EERI are not intended to evaluate process safety decision making, they do serve as helpful models upon which to develop an Engineering Process Safety Research Instrument (EPSRI) to assess a person's process safety decision making. Most of the research to date in this project has been focused on the development and validation of the EPSRI. In summary, anticipated outcomes upon conclusion of this project are (a) development of an EPSRI tool capable of assessing students' process safety decision-making, (b) construction of a virtual plant environment where multiple real-world factors may influence a students' process safety decisions, and (c) identification of best practices for integrating virtual environments into the classroom.

Methods

EPSRI Instrument Development

The EPSRI reflects the structure of the EERI [13] and DIT2 [12], which contain five dilemmas, followed by three decision options, and twelve considerations that fall into either pre-conventional , conventional, or post-conventional reasoning, as defined by Kohlberg and Hersh [15]. Pre-conventional considerations mostly focus on the outcome as it pertains to only the individual, conventional considerations focus on parties the individual directly interacts with, and post-conventional considerations are concerned with larger societal or environmental impacts. The dilemmas are meant to reflect process safety scenarios, and were adapted from case studies from the chemical safety board or personal experience. The three decision options that follow allow students to choose from one of two decision paths, or make no decision. Members of the research team were responsible for generating the dilemmas along with the options, and twelve considerations per dilemma. Researchers then reviewed all dilemmas, and generated an additional consideration for each dilemma which resulted in eight dilemmas with 15-17 considerations for the initial version of the EPSRI [16].

Following the generation of the content an external content validation study was completed. Content experts from chemical industry, chemical engineering education, and learning science fields were asked to review the EPSRI. Dilemmas were reviewed to ensure they represented realistic process safety scenarios that could occur in chemical industry. Considerations were reviewed to ensure they matched their perceived definitions, meaning they represented pre-conventional, conventional, or post-conventional reasoning accurately. The experts were also encouraged to provide feedback on the dilemmas, considerations, or any content areas that may have been omitted. As a result of the content validation study, one dilemma and eleven considerations were eliminated, and four dilemmas and eight considerations were revised. Further details on the methods of this study can be found in Butler *et al* [16].

After the content validation study was completed, a think aloud study was performed to verify if any changes may be necessary to the language used within the instrument for it to be understandable by its intended audience, senior chemical engineering students. The think aloud study resulted in clarification in the language in four dilemmas and eleven considerations. Subsequently, a large scale validation study was performed. In this study, an exploratory factor analysis was conducted on data obtained from a large scale implementation of the instrument in order to analyze the correlations between the items on a dilemma and within moral schema, and to determine the number of underlying latent variables [17]. A total of 223 responses from senior chemical engineering students were used in this study. The first test that was completed was the appropriateness of data which determined which items to eliminate based on their correlation with the other items within the dilemma. The second step was the factor extraction using principal component analysis and oblique rotation, which determined the number of underlying latent variables, and how the items were loading. Ideally, after this analysis, there should be four factors which contain the pre-conventional, conventional, post-conventional, and meaningless items. Meaningless items, or M-items, are nonsense considerations that are means to detect unreliable data in future implementations. The final step was completion of reliability analysis for each factor, which determined the strength of the correlations of the items that loaded onto a factor. As a result of this study, one dilemma and seven considerations were eliminated, and twenty-two of the considerations were revised.

Digital Immersive Environment Development

It was observed through implementation of the EPSRI that many students were approaching the instrument focused on selecting the most "safe" choice to each dilemma, which resulted in students showing mostly post-conventional lines of reasoning [18,19]. Although this is a positive outcome, it might not necessarily be reflective of how individuals will act in professional practice. In these situations, behavioral ethics are more likely to have an influence as discussed by Bazerman and Tenbrunsel [20]. In an attempt to provide a more realistic environment within which senior chemical engineering students could learn about process safety decision making, we have been working in collaboration with Filament Games on the development of a digital immersive environment.

The digital immersive environment follows a fifteen-day narrative arc where students are only allowed to interact with the system for a short period each day rather than play through the experience within one setting, which wouldn't accurately represent professional practice. Students serve as the senior plant engineer at a oil and gas facility located near the Gulf Coast. They are in charge of three operators, have a boss that checks in on them frequently, and have interactions with both the safety inspector that visits the plant, as well as other characters such as their daughter that help build additional emotive elements into the narrative. The narrative covers two key story events including a small scale rain storm that hits the plant followed by a hurricane that is directed right over the geographic location of the plant.

Over the course of the fifteen days, students will be tasked with making multiple types of decisions relevant to everyday concerns, such as an operator that has forgotten to stamp in their time card, to more involved safety based decisions, including whether to insist that the operators stay and work at the plant when faced with the upcoming hurricane directed for the area. Each decision provides the student with information that builds on the narrative and then asks them to choose between two outcomes. In some cases it is clear the difference between the two options whereas in other situations the choice options are much more nuanced, more accurately reflecting what decisions in professional practice would be. The immersive digital environment measures student performance by managing four resources: time, safety, personal reputation, and plant output. Decision options will have an impact on time management and then potential impacts on the other three metrics. When students hover over a decision choice they can observe which metrics are influenced by the choice but not the magnitude or the direction of the impact.

Reflection prompts are also integrated into the digital immersive environment to assist with measuring the forms of moral reasoning students are leveraging when making decisions. For instance, one reflection prompt states, “With no one around, the plant could have serious issues that impact the surrounding communities. How does this influence your decision?” This prompt will demonstrate how relevant the protection of local communities is to the student, a form of post-conventional reasoning. Another reflection prompt, “The last person was fired because of their bad reputation. How relevant is this to the last decision you made?,” focuses on the impact of the decision on the student themselves, a form of pre-conventional reasoning. Each reflection prompt has students make a selection from minimally relevant to very relevant, providing researchers with an understanding of the importance of these lines of moral reasoning in students’ approaches to decisions.

Current Status & Future Work

The EPSRI was taken by senior chemical engineers at the authors’ institutions at the beginning and end of the Fall 2018 academic term. These data represent the safety decision-making ability of students before and after typical safety and/or ethics instruction in the senior year. These results will be used to continue the validation process for the EPSRI. The authors also plan on contacting other chemical engineering educators who teach senior-level classes to use the EPSRI with their students to increase the sample size and reduce the impact of outliers on the overall factor analysis as part of the instrument validation process.

During the Spring 2019 academic term, the digital immersive environment will be integrated into courses at North Carolina State University, Rose-Hulman Institute of Technology, Rowan University, and the University of Connecticut for a pilot test. Student responses to game mechanics, decision points, and story elements will be monitored, and student academic motivation with the environment will be measured using the MUSIC model [21] to provide data for Research Question 2. Based on the results of this pilot test, the virtual environment will be modified to both enhance the user experience and to clarify any points of confusion on the part of the students. These modifications based on feedback are expected to conclude by the Fall 2019 academic term, where senior chemical engineers will also participate in the virtual environment. The students will complete the EPSRI before and after engaging with the environment. Data collected during these administrations of the EPSRI will then be compared to the data collected during the Fall 2018 term when no student interacted with the virtual environment to answer Research Questions 1 and 3. As supplemental data, information extracted from the environment related to students’ moral reasoning when making decisions will also be analyzed to expose their decision-making priorities.

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