Exploring Student Decision Making Trends in Process Safety Dilemmas using the Engineering Process Safety Research Instrument

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Background

Chemical industries have shown a long dedication to process safety because of the severity of accidents that can impact plants when a process safety incident occurs[1, 2]. The scope of aftereffects of process safety incidents can range from environmental degradation[3] to injuries and fatalities[4], and to industrial financial losses[5,6,7]. In response to and in prevention of these incidents, companies continue to implement a variety of process safety strategies.

Process Safety Strategies

Chemical industries have a tendency to approach process safety through a combination of two primary strategies: prevention through design (PtD) and decision making. PtD anticipates hazards and responds with designing solutions to mitigate those risks[8]. PtD encompasses a variety of safety techniques such as personal protective equipment (PPE), proper ventilation, explosion proof equipment, and sprinkler systems[9]. However, the effectiveness and capability of PtD is contingent on process safety decision making[3]. For example, in 2012 plant operators at the Chevron Refinery in Richmond, California identified a hydrocarbon process fluid leak. Plant assessment teams decided to resolve the leak with a repair clamp as the pipe could not be isolated without halting operations. To find the exact leak location, the Chevron Fire Department peeled away aluminum insulation from the pipe. In doing so, the leak rate accelerated, and a white hydrocarbon vapor cloud evolved and soon erupted. In this scenario, the PtD strategy was to tour the plant for defects which was successful in identifying the leak. However, the decision was made to continue operating the plant while the leak could not be isolated; this decision resulted in a disaster where 19 firefighters were in the proximity of a potentially fatal explosion[10]. Although PtD may be a successful strategy, human decision making will limit its effectiveness.

Ness represents the relationship between PtD and decision making with the “Swiss cheese” model. Each slice of cheese is a method of incident prevention, and each hole in the slice represents a poor decision. The potential alignment of the holes indicates where a failure might occur[11]. For example, Exxon Mobil’s Baton Rouge refinery suffered an alkylation unit fire in 2016 as a result of a series of poor decisions. The refinery management did not supply plant operators with written procedures to work around a malfunctioning plug valve gear box; in addition, the refinery’s safety culture embraced maintenance personnel disassembling the gearbox to manually open the valve contrary to protocol[12]. The combination of two or more errors, such as in this instance, demonstrate how the Swiss cheese model can be applied to process safety strategies. Since poor decision making can inhibit the benefits associated with PtD, this paper will focus on decision making.

Process Safety Instruction

In 1984, the Bhopal Disaster in India[13] shook industry leaders and educators of the American Institute of Chemical Engineers (AIChE). To mitigate these types of disasters, AIChE developed the Center for Chemical Process Safety (CCPS) for manufacturers and government agencies to share guidelines and process safety methods[14]. In addition, AIChE expanded into institutions through the development of the Safety and Chemical Engineering Education (SAChE) group in 1992 which offers free resources to any AIChE member[15]. This program provides a variety of online process safety courses, ranging in difficulty and form, such as presentations, readings, and videos. The use of these resources is often encouraged as a supplement to a student's pre-established institution's curriculum. Despite these early strides, as of 2009, only 25% of universities implemented process safety into curriculum[16]. After investigating the T2 Laboratories, Inc., chemical explosion, the Chemical Safety Board (CSB) recommended that ABET begin coordinating with AIChE so accreditation would require hazard education[17]; these requirements were added by 2010[18]. Today, ABET's desired student outcome item 2 in the 2019-2020 accreditation criteria for engineering states, "*students should have* an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and… environmental… factors"[19].

Engineering curricula are already constrained with expectations and deliverables, so it is difficult to add an entire course dedicated to process safety without further condensing other core courses[20]. Alternatively, process safety can be distributed as a recurring theme in other courses, as an additional module to a current course[21], or as co- or extra-curricular content[22]. Outside of the classroom, SAChE offers Process Safety Certificates which can be achieved through online modules and quizzes[15].

In addition to process safety requirements, ABET's desired student outcomes item 4 states, "*an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in a global, economic, environmental, and societal context*"[18,19]; institutions often address this outcome by including an ethics based course or distributing the topic into other courses. In the context of process safety, this training is critical in regard to ethical dilemmas observed and discussed in industry. Although integration of ethics and process safety instruction is common, most often these units do not place a particular emphasis on the decision-making process and where issues may occur that could detriment proposed safety strategies. This paper will seek to better understand how students approach these decisions within a process safety context.

Research Questions

The purpose of this work is to determine how senior chemical engineering students approach process safety dilemmas and whether they find specific types of dilemmas to be more challenging for decision making than others. In addition, this work will explore the effects of process safety curriculum on how students respond to the same dilemmas. The formal research questions guiding this work are:

1. What types of process safety ethical dilemmas are the most difficult for students to determine a course of action?
2. How does course instruction in process safety affect decision making approaches?

Methods

Study Design and Data Collection

During the 2019 spring semester, the Engineering Process Safety Research Instrument (EPSRI) was distributed to 274 senior chemical engineering students from eight ABET-accredited institutions; the breakdown by institution is shown in Table 1. The instrument was administered electronically as either an in-class or homework assignment within a senior level course.

Table 1. Distribution of EPSRI Survey Responses based on Institution.

Institution	1	2	3	4 *	5 *	6 *	7 *	8 *
N (Total 274)	6	53	3	69	97	18	17	11

Institutions with an asterisk provided details regarding their process safety and ethics curriculum.

The second portion of the study investigated the relationship between an institution's curriculum and the students' responses on the EPSRI. To understand an institution's curriculum, a survey, supplementing the EPSRI, was distributed to identify core courses and methods used to specifically teach process safety and ethics. Of the eight institutions who participated in the EPSRI study, only five institutions participated in the survey which are marked with an asterisk in Table 1. This survey specifically sought to obtain information on the following:

- Use of classroom discussion on process safety
- Whether an engineering ethics course was used or a generic ethics course
- Use of a dedicated process safety course versus implementing process safety as a module

Engineering Process Safety Research Instrument

The design of the EPSRI is based on the Defining Issues Test 2 (DIT2)[23-26] and utilizes levels of moral reasoning described in Kohlberg's theoretical framework[27]. The goal of the EPSRI is to investigate how senior chemical engineering students approach process safety decision making and the level of moral reasoning which they apply when making these decisions. Similar to the DIT2, the EPSRI has students respond to five ethical dilemmas; however, the EPSRI's dilemmas were specifically designed around process safety incidents, such as those published by the CSB, and were reviewed by chemical engineering educators and researchers and industry professionals for content validity[28]. Table 2 provides an overview of each dilemma to illustrate the diversity of process safety dilemmas within the EPSRI. Students are asked to respond to each dilemma by selecting one of three options. Two options are potential solutions to the dilemma; the third option is "Can't Decide". After selecting an option for each dilemma, students are asked to gauge the importance of considerations relative to their decisions. There are 12 to 15 of these considerations per dilemma, and they are mapped to Kohlberg's levels of moral reasoning[29]. Although the EPSRI collects data on students' ratings and rankings of considerations, only the responses to each dilemma were analyzed as part of this study.

Table 2 Summary of dilemmas in the EPSRI

Dilemma	Summary
1	The participant is a design engineer in charge of replacing hoses carrying a dangerous chemical. They must decide whether to use an inexpensive hose that requires monthly replacements, or an expensive hose that requires annual replacements.
2	The participant is an engineer for the gasoline industry working at a plant in the suburbs of a city. A hurricane is forecasted to strike their chemical plant, and they must decide between soliciting volunteers to manage the plant or relying on plant safety structure.
3	The participant is a recent graduate working at a start-up company. On the first day of the job, they witness a leaky valve and are told by a senior engineer not to report it. They must decide whether to report the leak to the manager or follow the engineer's suggestion and ignore it.
4	The participant is an operator at an oil refinery and a hazardous chemical pump valve malfunctions while in the middle of a process.The test taker must decide between contacting a supervisor before proceeding or dismantling the top portion of the valve in order to complete the task.
5	The participant works as R&D in a small company that relies on an environmentally unfriendly additive for production and must decide whether to research a replacement chemical or to warrant that the company's usage of the additive is insignificant enough to damage the environment.

Data Analysis

The first research question investigated what types of ethical dilemmas were most difficult for students to reason through. We selected to analyze at the dilemma level as each situation provided a unique context for students to reason through what should be done to ensure process safety principles were followed. We also selected to look at the variability in students who selected the option of "Can't Decide" in comparison to those who were able to make a final decision selection of "Option A" or "Option B". The rationale behind this data analysis decision was to look for areas where students may have struggled with selecting one option or another. Although two options were provided to each dilemma, the option choices didn't always specifically align with an existing ethical theory making it difficult to perform comparisons on if students were favoring one ethical approach to decision making over another. Choosing the Can't Decide option is interpreted as potentially being an acknowledgement of complexity since students couldn't clearly select one alternative or another. The number of students who selected Option A or B were tallied together and compared to the number of students who selected Can't Decide. A Chi-Square test was used to find if there were any statistically significant differences between the proportion of students selecting Option A or B in comparison to those that selected Can't Decide between pairs of dilemmas. As multiple comparisons were being made, each p-value was adjusted using the Bonferroni factor to eliminate the increased probability of false positives[30].

The second research question involved determining if the process safety curriculum at each surveyed institution had an effect on how students made process safety decisions. Table 1 showed that five institutions responded to the curriculum survey; based on these responses, the EPSRI results could be reviewed to determine the impacts of (1) the use of in-class discussions, (2) including coursework specifically dedicated to engineering ethics or generic overall ethics, (3) having a course dedicated to teaching process safety compared with incorporating process safety modules into other courses in the curriculum, and (4) the use of SAChE resources to teach process safety. Sample sizes for each comparison are provided in Table 3. For the accuracy of this analysis, only institutions which definitively stated their instruction approach were counted towards this analysis; this causes the cumulative sample size per comparison to vary.

Table 3: Population sizes of curriculum analysis.

	Type of Process Safety Instruction	**Institutions**	**Sample Size**
1	In-Class Discussions	4,5,6	184
	No Discussions	7,8	28
2	General Ethics Course	4	69
	Engineering Ethics Course	5,8	108
3	Dedicated Process Safety Course	5,6,7	131
	Integrated Process Safety Course	4,8	81
4	Utilization of SAChE Modules	4,5,8	177
	No SAChE Modules	6,7	35

Each of the four comparisons looked at the selection of an option versus the selection of Can't Decide. Each comparison is made on a per dilemma basis since student responses can vary across dilemmas. Based on the institution survey answers, the areas of analysis were Discussion versus No Discussion, Engineering Ethics versus Generic Ethics, Dedicated Process Safety Courses versus Incorporated Process Safety Courses, and the use of SAChE modules versus no SAChE modules. Each population of responses was then subject to a Chi-Square test to analyze significance. Similar to the first research question, a Bonferroni factor[30] was used with the Chi-Square tests to adjust the p-value based on the multiple comparisons being performed.

Results and Discussion

In an earlier version of the EPSRI, a think-aloud protocol was followed to identify holistic codes for how students reason through dilemmas; one of these codes was an acknowledgment of complexity[31]. This finding inspired further study into what students specifically found to be difficult when making process safety decisions; the first research question is "*What types of process safety ethical dilemmas are the most difficult for students to determine a course of action?*". To understand the types of dilemmas which are difficult, the dilemmas themselves were compared. How students responded to each dilemma is shown in Table 4.

Table 4. EPSRI decision responses.

Dilemma	Decision	Quantity
1	Option A or B	258
	Can't Decide	16
2	Option A or B	181
	Can't Decide	93
3	Option A or B	262
	Can't Decide	12
4	Option A or B	256
	Can't Decide	18
5	Option A or B	247
	Can't Decide	27

By initial observation, Dilemma 2 has the highest number of student selections of the Can't Decide option suggesting it may be more difficult for students to make a decision in this dilemma in comparison to other dilemmas. To determine if a statistical difference exists between pairs of dilemmas, a Chi-Square test was performed. Dilemma pairs are made between any two dilemmas; pairs and Chi-Square results are shown sequentially in Table 5.

Table 5. The results of Chi-Square comparisons including the Bonferroni adjustment factor. P-values with three asterisks show where there is a highly statistically significant relationship.

Dilemma A	Dilemma B	P-value
1	2	p < 0.001***
	3	p = 1.00
	4	p = 1.00
	5	p = 0.405
2	3	p < 0.001***
	4	p < 0.001***
	5	p < 0.001***
3	4	p = 1.00
	5	p = 0.065
4	5	p = 0.805

Can't Decide selections in Dilemma 2 were highly significant in comparison to any other paired dilemma after applying a Bonferroni adjustment factor for multiple comparisons. Only when a pair of dilemmas include Dilemma 2 does the pair have a highly significant relationship; any other compared pairs were found to be not significant. This result shows that there were significantly more Can't Decide responses to Dilemma 2 as opposed to Option A or B responses when compared to other dilemmas in the EPSRI. When seeking to explain why this takes place, we can look at a summary of Dilemma 2's prompt for insight:

> *The second dilemma in the EPSRI places the students into the position of a plant engineer at a chemical company in the suburbs of a major city. There's a severe hurricane heading towards the plant, and if the plant floods, there is the possibility of extreme hazardous events such as an explosion. It is possible that the storm is not as severe as predicted and that the plant will not fail, but the student is asked to make the decision. Should they solicit volunteers to help the plant weather the storm, or should they rely solely on the plant's construction and hope it holds out. Students could also choose the Can't Decide option.*

Individuals' most often make decisions in favor of short-term rewards, in this case, the avoidance of immediate hazards[32]. In this dilemma, students are observed to resort to responding to the dilemma with Can't Decide when neither option seems to provide a way to minimize leaving a population at risk of associative hazards. Because the EPSRI does not offer a short-term reward option to eliminate immediate threats, the EPSRI reveals students' difficulty in breaking from their trend.

An alternative interpretation is that only the decision of Dilemma 2 directly compares utilitarian and deontological ethical theories. This comparison is comparable to the controversial trolley-footbridge dilemma created by Phillippa Foot; this ethical dilemma has been acknowledged as difficult as the reader is tasked with deciding to save the lives of five by deliberately sacrificing one[33]. Dilemma 2 of the EPSRI differs from the trolley-footbridge dilemma by supplying the Can't Decide option which provides students with a choice that doesn't force a decision to be made. This process can help avoid the debate over which ethical theory should be upheld within the provided context and allow for students to acknowledge difficulty or complexity associated with the decision.

The second research question asked, *"How does course instruction in process safety affect decision making approaches?"* As discussed earlier in the paper, there are multiple ways to teach process safety including classroom-based discussions, ethics-based instruction, incorporation of new coursework, and use of SACHE modules. Using the Chi-Square test, it was observed that there was no statistical significance between pairs of dilemmas for any of the teaching approaches investigated.

In the analysis of discussion-based teaching strategies, the majority of p-values ranged between 0.728 and 0.988 with one of 0.152. These results are shown in Table 6. The results suggest no significant differences between students that couldn't decide on a decision and those that could make a choice based on students that had discussions in class and those that did not. This result comes as a surprise given that discussion is a key component of active learning which has been studied to show 'improvements' for learning in in-person classes[34]. Perhaps the discussion in the process safety courses observed lacked an emphasis on the complexity involved in decision making. The curriculum survey that was administered only inquired about the existence of process safety discussions and not the nature or extent of its implementation.

Table 6. Comparison of institutions which reported using classroom discussions as a method of process safety instruction.

Dilemma	Population	Decision	Quantity	P-value
1	Discussion	Option A or B	171	p = 0.988
		Can’t Decide	13	
	No Discussion	Option A or B	26	
		Can’t Decide	2	
2	Discussion	Option A or B	124	p = 0.152
		Can't Decide	60	
	No Discussion	Option A or B	15	
		Can't Decide	13	
3	Discussion	Option A or B	177	p = 0.952
		Can’t Decide	7	
	No Discussion	Option A or B	27	
		Can’t Decide	1	
4	Discussion	Option A or B	175	p = 0.944
		Can't Decide	7	
	No Discussion	Option A or B	27	
		Can't Decide	1	
5	Discussion	Option A or B	168	p = 0.728
		Can’t Decide	16	
	No Discussion	Option A or B	25	
		Can’t Decide	3	

With regards to students that received ethics instruction, the p-values ranged from 0.050 for Dilemma 2 to 0.254 for Dilemma 3 indicative of no statistically significant difference. These results are shown in Table 7. One notable point of interest was that the students taking the generic ethics course had a greater ratio of choosing Option A or B over choosing Can’t Decide. Although there is no significant difference between the two, more students in the generic ethics courses selected a definitive choice in place of the Can’t Decide option. Preference on the approach to teaching ethics has been debated. Matteson and Richter suggest that generic ethics courses are more effective for engineering students because they teach a wider variety of ethical theories, allowing students to apply the solutions to other applications such as process safety[35].

In contrast, Donahue emphasizes the importance of discipline specific ethics as that approach adds value to the content being discussed[36]. The results of the analysis best align with the findings of Walther *et al* which suggests too many variables exist to evaluate one method as "better" than another[37].

Table 7. Comparison of institutions which reported using engineering ethics-based courses.

Dilemma	Population	Decision	Quantity	P-value
1	Engineering Ethics	Option A or B	97	p = 0.070
		Can't Decide	11	
	Generic Ethics	Option A or B	67	
		Can't Decide	2	
2	Engineering Ethics	Option A or B	66	p = 0.050
		Can't Decide	42	
	Generic Ethics	Option A or B	52	
		Can't Decide	17	
3	Engineering Ethics	Option A or B	103	p = 0.254
		Can't Decide	5	
	Generic Ethics	Option A or B	68	
		Can't Decide	1	
4	Engineering Ethics	Option A or B	102	p = 0.556
		Can't Decide	6	
	Generic Ethics	Option A or B	67	
		Can't Decide	2	
5	Engineering Ethics	Option A or B	94	p = 0.058
		Can't Decide	14	
	Generic Ethics	Option A or B	66	
		Can't Decide	3	

In the comparison between students with a dedicated process safety course and those where process safety is incorporated into other core courses, the Chi-Square test showed no statistical significance between these pairs and the proportion of students choosing Option A or B or choosing Can't Decide. P-values ranged from 0.114 to 0.811. The final analysis examined whether the use of SAChE process safety modules had an impact on the decision choices of senior chemical engineering students. The p-values for the SAChE process safety module were also not statistically significant, with a range from 0.390 to 0.697. Although the results do not show significant differences with the use of either a dedicated process safety course or the inclusion of SAChE modules, they do not imply these methods are ineffective in teaching process safety. Alternatively, the EPSRI is focused on observing the nuances associated with ethical decision making in process safety; whereas the observed methods may have approached process safety instruction with a focus on prevention through design.

Study Limitations

This study was conducted with 274 second-semester, senior chemical engineering students from eight institutions. As shown previously in Table 1, the sample size per institution varies from as few as three to as many as ninety-seven students. This variance suggests the data may have limited generalizability, particularly in the curriculum analysis since some sample populations were much smaller than others (see Table 3).

The first study compares the selections of Option A and B to the selection of Can't Decide on a dilemma basis and interprets the selection of the latter as an acknowledgment of complexity. This might not always be the case as students may select Can't Decide if they are discontent with the provided two selection options. In addition, students may have selected Option A or B without devoting ethical reasoning to support their decision following the phenomenon of moral dumbfounding[38].

Conclusion

The chemical process industry addresses process safety concerns through a variety of strategies which can be summarized into prevention through design (PtD) and decision making. Regardless of the industry's efforts and institutions adaptation of curriculum, process safety incidents continue to occur. These failures can often be traced back to a series of decisions which inhibit PtD safety measures; as such, investigating process safety decision making is critical to mitigate potential future incidents. This study examined student's difficulty while decision making when confronted with process safety dilemmas with two potential solutions and a Can't Decide option. It was observed that students struggled the most in a dilemma where both available options left a specific target population in imminent risk. Literature suggests individuals resort to resolving urgent risks first when making decisions, but since in this dilemma neither potential solution resolves all threats, the students may be left at a loss of how to proceed[32]. In this situation, the students chose the Can't Decide option as they were potentially confounded between the proposed solutions, so choosing Can't Decide was a way to acknowledge the complexity of the dilemma, or answer without the discomfort of not fully resolving the problem.

This study also investigated the effects of an institution's process safety curriculum on how students' make decisions in process safety contexts. In an attempt to better understand how process safety course instruction affects decision making, the sample population was distributed based upon approaches to process safety instruction. The results showed no significant differences amongst the students' decision making tendencies based on their curriculum such as dedicated courses to process safety or use of classroom discussions. Process safety instruction requires layers of strategies for the best outcome, utilizing both PtD and decision making. The EPSRI only assesses a student's approach towards process safety decision making, so if their institution focused on PtD or hazard identification, this process safety knowledge might not be differentiated in the EPSRI.

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References

[1] J. Champion, S. Van Geffen, and L. Borrousch, "Reducing Process Safety Events: An approach proven by sustainable results," *Process Safety Progress*, vol. 36, no. 4, pp. 326-337 Oct. 2017.

[2] U. Bruyere, M. Fox, and C. Watson, "Process Safety Fundamentals Training for First Level Leaders," *Institution of Chemical Engineers Symposium Series*, vol. 155, pp. 529-535, 2009.

[3] U.S. Chemical Safety and Hazard Investigation Board. Caribbean Petroleum Tank Terminal Explosion and Multiple Tank Fires. Report No. 2010.02.I.PR, 2015. [Online]. Available: https://www.csb.gov/file.aspx?DocumentId=5965. [Accessed Jan 9, 2020].

[4] U.S. Chemical Safety and Hazard Investigation Board, "Non-Condensable Gas System Explosion at PCA DeRidder Paper Mill," Washington, DC, Investigation Report, 2017-03-I-LA, April 24, 2018.

[5] US Chemical Safety Board, "Fire and Explosion at Philadelphia Energy Solutions Refinery Hydrofluoric Acid Alkylation Unit," Factual Update. No. 2019-06-I-PA. Oct. 16, 2019.

[6] Phillips, S. (2019, July 19). "Refinery Explosions Raise New Warnings about Deadly Chemical". National Public Radio, July 2019. [Online]. Available: https://www.npr.org/2019/07/19/742367382/refinery-explosions-raise-new-warnings-about-deadly-chemical [Accessed Jan 9 2020].

[7] N. Dechy, T. Bourdeaux, N. Ayrault, M. Kordek, and J. Le Coze, "First lessons of the Toulouse ammonium nitrate disaster, 21st September 2001, AZF plant France," *Journal of Hazardous Materials*, vol. 111, pp. 131-138, 2004.

[8] Biddle E, Afanuh S. “NIOSH Workplace Design Solutions: supporting Prevention through Design (PtD) using business value concepts.” *Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS (NIOSH),* Publication No. 2015-198. 2015.

[9] D. Crowl and J. Louvar, "Concepts to Prevent Fires and Explosions," *Chemical Process Safety Fundamentals with Applications, Third Edition, Massachusetts: Prentice Hall,* pp. 317-374, 2011.

[10] US Chemical Safety Board, "Chevron Richmond Refinery Pipe Rupture and Fire," Final Investigation Report. No. 2012-03-I-CA. Jan. 2015.

[11] Ness, A. “Lesson learned from recent process safety incidents.” *Center for Chemical Process Safety,* 23-29. 2015. [Online]. Available: https://www.aiche.org/sites/default/files/cep/20150323.pdf. [Accessed Jan 9, 2020].

[12] US Chemical Safety Board, "Key Lessons from the ExxonMobil Baton Rouge Refinery Isobutane Release and Fire," Safety Bulletin. No. 2016-02-I-LA. Nov. 22, 2016.

[13] E. Broughton, “The Bhopal disaster and its aftermath: a review”, *Environmental Health: A Global Access Science Source,* vol. 4,6, May 2005, https://doi.org/10.1186/1476-069X-4-6

[14] "History," Center for Chemical Process Safety. [Online]. Available: https://www.aiche.org/ccps/about/history. [Accessed Dec 01, 2019].

[15] "About," Safety and Chemical Engineering Education. [Online]. Available: http://www.sache.org/ [Accessed December 01, 2019].

[16] Louvar, J. F. “Safety and Chemical Engineering Education - History and Results.” *AIChE*. vol. 28, no.2. DOI 10.1002/prs.10315. [Accessed April 13, 2009].

[17] US Chemical Safety Board, "T2 Laboratories, Inc. Runaway Reaction," Investigation Report. No. 2008-3-I-FL. Sept. 2009.

[18] B. Vaughen, "An Approach to Help Departments Meet the New ABET Process Safety Requirements," *Chemical Engineering Education*, vol. 46, no. 2, pp. 129-134. 2012.

[19] ABET. (2018). Criteria for Accrediting Engineering Programs, 2018 – 2019. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/#GC3 [Accessed Jan 9 2020].

[20] S. Dee, "Process Safety in the classroom: The current state of chemical engineering programs at US universities," *American Institute of Chemical Engineers*, vol. 34, pp. 316-319, 2015. [Online]. Available: AIChE, https://doi.org/10.1002/prs.11732. [Accessed January 9, 2020].

[21] G. McRae, 10.491 Integrated Chemical Engineering II. *Massachusetts Institute of Technology*. [Online]. Available: MIT OpenCourseWare, https://ocw.mit.edu/courses/chemical-engineering/10-491-integrated-chemical-engineering-ii-spring-2006/. [Accessed January 9, 2020].

[22] M. Dillon, “WVU Offers First-of-its-kind Process Safety Boot Camp to Chemical Engineering Students,” *WVUToday Archive*, April 19, 2013. [Online]. Available: WVUToday-Archive, http://wvutoday-archive.wvu.edu/n/2013/04/19/wvu-offers-first-of-its-kind-process-safety-boot-camp-to-chemical-engineering-students.html. [Accessed January 9, 2020].

[23] J. Rest, L. Edwards, and S. Thoma, "Designing and Validating a Measure of Moral Judgment: Stage Preference and Stage Consistency Approaches," Journal of Educational Psychology, vol. 89, no. 1, pp. 5-28, 1997.

[24] J. Rest, S. Thoma, D. Narvaez, and M. Bebeau, "Alchemy and Beyond: Indexing the Defining Issues Test," Journal of Educational Psychology, vol. 89, no. 3, pp. 498-507, 1997.

[25] J. Rest, D. Narvaez, M. Bebeau, and S. Thoma, "A Neo-Kohlbergian Approach: The DIT and Schema Theory," in Educational Psychology Review, vol. 11, no. 4, pp. 291-324, 1999.

[26] J. Rest, M. Bebeau, and S. Thoma, "DIT2: Devising and Testing a Revised Instrument of Moral Judgement," in Journal of Educational Psychology, vol. 91, no. 4, 1999. pp. 644-659.

[27] L. Kohlbeg and R. Hersh, "Moral Development: A Review of the Theory," vol. 16, issue 2, pp. 53-59, 1997.

[28] B. Butler, D. Anastasio, D. Burkey, M. Cooper, and C. Bodnar, "Work in Progress: Content Validation of an Engineering Process Safety Decision-making Instrument (EPSRI)," in American Society of Engineering Education Annual Conference and Exposition, ASEE 2018, Salt Lake City, UT, USA, June 24-27, 2018. [Online]. Available: ASEE, https://peer.asee.org/31279. [Accessed January 9, 2020].

[29] B. Butler. C. Bodnar, M. Cooper, D. Burkey, D. Anastasio, "Towards understanding the moral reasoning process of senior chemical engineering students in process safety contexts," *Education for Chemical Engineers*, vol. 28, pp. 1-12, 2019. Available: ScienceDirect, https://doi.org/10.1016/j.ece.2019.03.004. [Accessed January 9, 2020].

[30] J. Bland, and D. Altman, "Multiple significance tests: the Bonferroni method," BMJ, 310:170, 1995. Available: theBMJ, https://doi.org/10.1136/bmj.310.6973.170. [Accessed January 15, 2019].

[31] C. Bodnar, E. Dringenberg, B. Butler, D. Burkey, D. Anastasio, M. Cooper, “Revealing the Decision-Making Processes of Chemical Engineering Students in Process Safety Contexts,” Chemical Engineering Education, vol. 54, no. 1, pp. 1-9, 2020.

[32] G. Ainsli, "Précis of Breakdown of Will," *Behavioral and Brain Sciences*, vol. 28, pp. 635-673, 2005. Available: Cambridge University Press, https://doi.org/10.1017/S0140525X05000117. [Accessed January 9, 2020].

[33] J. Thomson, "The trolley problem. (ethics of killing and letting die)," *The Yale Law Journal*, vol. 94, no. 6, pp. 1395-1415, 1985. [Online]. Available: The Yale Law Journal, https://digitalcommons.law.yale.edu/ylj/vol94/iss6/5. [Accessed January 9, 2020].

[34] B. Millis, “Active Learning Strategies in Face-to-Face Courses,” *The Idea Paper*, no. 53, 2012. [Online]. Available: Eric Institute of Education Sciences, https://eric.ed.gov/?id=ED565290. [Accessed January 9, 2020].

[35] J. Matteson, and D. Richter, "Broadening and deepening engineering students' perspectives on morality and ethics," in *American Society of Engineering Education Pacific Southwest Section Meeting, Tempe, Arizona, USA, April 20, 2017*. [Online]. Available: ASEE, https://peer.asee.org/29206. [Accessed January 9, 2020].

[36] S. Donahue, “Discipline specific ethics,” *Design Philosophy Papers*, Vol. 2, Iss. 2, pp. 95-101, 2004. [Online]. Available: Taylor and Francis Online, doi: http://dx.doi.org/10.2752/144871304X13966215067877. [Accessed January 9, 2020].

[37] J. Walther, N. Kellam, N. Sochacka, and D. Radcliffe, “Engineering Competence? An Interpretive Investigation of Engineering Students' Professional Formation,” Journal of Engineering Education, vol. 100, no. 4, pp. 703-740, 2011. [Online]. Available: Wiley Online Library, https://doi.org/10.1002/j.2168-9830.2011.tb00033.x. [Accessed January 9, 2020].

[38] M. Timmons and D. Jacobson, “Moral Dumfounding and Moral Stupefaction,” *Oxford Studies in Normative Ethics*, vol. 2. Oxford University Press, 2013.