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Criteria Conundrum: Engineering Students' Beliefs about the Role of Competing Criteria in Process Safety Judgements

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Introduction

Engineering practitioners are responsible for making judgements related to process safety situations, which could impact the probability of a safety incident occurring. These incidents can have devastating repercussions, potentially resulting in injury or fatality of personnel [1]. Incident reports and literature suggest that many of these incidents may be attributed to poor judgements where engineers must juxtapose conflicting criteria (e.g., choosing between prioritizing greater safety or higher production) [1]–[10]. Although educators have built process safety content into the undergraduate engineering curriculum [11], [12], not much is known about how engineers will reconcile their learned safety-conscious values from process safety courses with their actual judgments in real-life industrial contexts. To evaluate how chemical engineering students may approach process safety judgements upon entering industry, this study looks at students' espoused beliefs and compares them to their simulated behaviors. While our beliefs can act as a predictor of our future behaviors [13] contextual factors, such as social pressures, can result in behaviors that do not directly reflect our espoused beliefs [14]. We can, however, better predict our future behaviors by engaging in self-reflection related to our previous behaviors, thus helping to build awareness for future judgements [15]. Due to the inherent complexity associated with judgements in a process safety setting, a lack of awareness may cause engineering practitioners to behave outside of their typical set of beliefs, sometimes resulting in poor or uninformed judgements.

We are studying chemical engineering students to understand how their beliefs and behaviors compare in the context of process safety judgements and how they react to any differences so that we can prepare students to acknowledge the inherent complexity of how they approach judgements. Specifically, this study seeks to answer two research questions: *(1) What are engineering students' beliefs about how they would approach process safety judgements with competing criteria?* and *(2) How do these students react to the process of comparing their beliefs and behaviors in process safety judgements with competing criteria?* Understanding chemical engineering students' intentions through their espoused beliefs will help us better understand what influences students' beliefs about how to approach process safety judgements, answering the first research question. By answering the second research question, we provide empirical evidence of how the process of reflecting on gaps between beliefs and behavior might develop chemical engineering students as more reflective, deliberate, and realistic decision makers.

Background

This section will provide an overview of chemical process safety in engineering education and how it is related to beliefs and judgements in that context. The process safety industry is marked by several incidents involving competing criteria that engineering staff responded to with poor judgements, contributing to the conceptual framework for this study.

Process Safety

The chemical process industry frequently handles hazardous chemicals and manufacturing equipment that, when used improperly, can be detrimental to their workers' health, the environment, and the surrounding community. Thus, mitigating process safety incidents continues to be at the forefront of improving process safety education. The United States Chemical Safety and Hazard Investigation Board (CSB) has investigated over 130 process safety incidents and has given 913 recommendations to companies and chemical plants over the last 20 years [16]. To respond to the regularity of process safety incident occurrence, the industry has focused on process safety training in industry through HAZOP/LOPA (Hazard Operability Assessment/Layers of Protection Analysis) [17], hazard analysis [18], and risk assessment [19]. Although improvements to risk management strategies and automation techniques have been made, process safety incidents continue to persist in industry [1], [20]. To prepare engineering students to work in industry, many institutions have incorporated process safety content in the undergraduate education curriculum as well [21]–[23]. The continual occurrence of process safety incidents shows that these educational measures have not been successful in preventing all occurrence of these disasters.

Though many recent process safety incidents have been preventable as the cause was known to the organization ahead of time [24], the role of engineering judgement in those situations is typically overlooked. By reviewing chemical process safety incident reports, we can evaluate incidents where engineers made poor judgements when faced with a situation with competing criteria. One such example is the BP Texas City Refinery explosion in 2005. According to the Chemical Safety Board (CSB), one of the main causes of this incident was the unclear instructions provided by the engineering leadership on site [24]. Warning signs of the incident had been present for multiple years, and no one within the corporation intervened to solve the issue [9]. As a result, 15 workers were killed and 180 more were injured in a series of explosions [9], [24]. A similar case-study is shared in the Chevron Refinery incident in 2012, where engineering judgement did not address leak hazards, instead choosing to maintain production, which resulted in an explosion that put plant workers' lives at risk [8]. In both process safety incidents, the employees may have lacked awareness of how they make judgments in scenarios with competing criteria [8], [9]. Chemical process companies may emphasize safety in company mottos or culture [25], yet in practice, demands for productivity, interpersonal relationships, or budget may compete with the need for safe practice [8], [26]. As such, when engineers encounter judgements with competing criteria, they may be unfamiliar with how they will make these judgements. When engineers are not aware of how they will make judgements, a pathway exists for them to deviate from their priorities, such as safety. Improving engineers' awareness of how they tend to behave when they approach process safety judgements may mitigate process safety disasters, therefore limiting the repercussions of real-world consequences. If engineers and other industry professionals are responsible for judgements to prevent process safety incidents, then educators need to prepare them for these situations to reduce their occurrence.

Student Beliefs and Behavior

Beliefs create our basic understanding of the world around us, aiding in our response to difficult judgements under pressure [27]. Beliefs can be developed through personal experiences, the knowledge shared with us by others, or other shared cultural values [28]. By the time students enter industry, they may have developed beliefs based solely on classroom theory and the limited exposure to relevant experiences or internships [13], [28]. If students are faced with a difficult judgement in the process safety industry, they might not have a well-defined set of beliefs to guide their behaviors for that situation. Having a well-defined set of beliefs "allows its owner to feel more secure and grasp on to certainty, despite the myriad of choices, decisions, and unknowns that must be constantly navigated" [27, p. 4]. This feeling of security makes us trust our beliefs, helping us to make better informed judgements in our behavior. Different types of beliefs can be an indicator of the behaviors we use in certain situations [13], [29]. The reasoned action approach (RAA) suggests that there are three types of beliefs that can define our behavioral intentions and thus predict our behavior: behavioral, normative, and control beliefs [13]. Behavioral and normative beliefs focus on the consequences and social ramifications that one perceives their behavior to have. Control beliefs focus on an individual's self-efficacy in their ability to execute the desired behavior. While these three beliefs designations may not always accurately predict behavior, research has shown these types to contribute the most. Other research suggests that iterative self-reflection and reconciliation of our past behavior can help develop more robust beliefs about our future actions [15].

Beliefs occur at both a conscious (espoused) and subconscious (implicit) level which are derived from our socialization [29]. It is difficult to effectively study implicit beliefs, making them a wild card when comparing an individual's beliefs to their behaviors. This is problematic for researchers because our implicit beliefs may influence our actions, but our conscious mind retains no active memory of the development of such a belief [30]. It is common for our espoused beliefs to not match our behaviors [14] suggesting that the nuances of our implicit beliefs may be missing, or there are contextual factors at play that influence one's decision-making. Behavioral ethicists encourage individuals to create awareness in decision-making situations by being reflective of their choices (behavior) rather than adhering to a specific set of values stipulated by themselves or others [31]. Making judgements with increased awareness can help individuals "make decisions that are more in line with their ethical standards" [31, p. 99]. This approach to reconciliation between espoused beliefs and future actions serves as the grounding methodology to this study. Thus, we posit that asking students to confront the differences in their espoused beliefs and their behaviors can help them bring awareness to weaknesses in their approach to making process safety judgements.

Conceptual Framework

As a part of this project, we developed a conceptual framework around criteria that engineers consider through their process safety judgements: safety, leadership, relationships, production, spending, and time (Table 1). These criteria emerged from process safety literature and Chemical Safety Board (CSB) case studies [5]–[8] as well as non-engineering industries that rely on practitioner judgement [2], [3], [10], [32]. Moreover, this conceptual framework has been leveraged in other recent works regarding engineering students' judgements [33]–[35]. This conceptual framework enables participants in this study to discuss their espoused beliefs by providing shared language that is grounded in literature [34].

Table 1. Definitions of Criteria (Conceptual Framework)

Criteria	Definition	Icon
Safety	Preventing injuries to people/plant machinery or environmental effects that may occur from chemical leaks that get into the air or waterways.	
Leadership	How you manage employees and your reputation as a supervisor. Authority, mentorship, credibility.	

Relationships	How your coworkers see you as a person and the way in which you may care for them and other important people in your life, such as your family. Connections with people.	
Production	The bottom line that your company or employer wants you to meet, output from the plant facility. Getting things done.	
Spending	Sticking to company budgets and reducing expenses.	
Time	Your availability to spend time with family, participate in hobbies, and invest in your career.	

Methods

This pilot study is part of a larger study investigating chemical engineering students' approach to process safety judgements [34], [36]. There were five senior-level chemical engineering students recruited from a process safety course at a mid-Atlantic institution for this pilot. Due to scheduling complications, only three students completed all phases of the data collection process. The participants were selected at random after they filled out an interest and consent form. Their data has been de-identified as part of the analysis process and pseudonyms were assigned to the students (Alex, Bradley, and Charlie). These students were all male, senior-level chemical engineering students. The selected participants then completed the three-phase pilot research study that took place over the course of the spring 2022 semester. IRB approval was obtained prior to data collection and analysis.

The methodological approach is outlined through the following three study phases: (1) Beliefs Interviews, (2) Contextual Intervention, and (3) Reconciliation Interviews (Fig. 1). The interview protocols for phase 1 and phase 3 can be found in Appendix A and Appendix B, respectively.

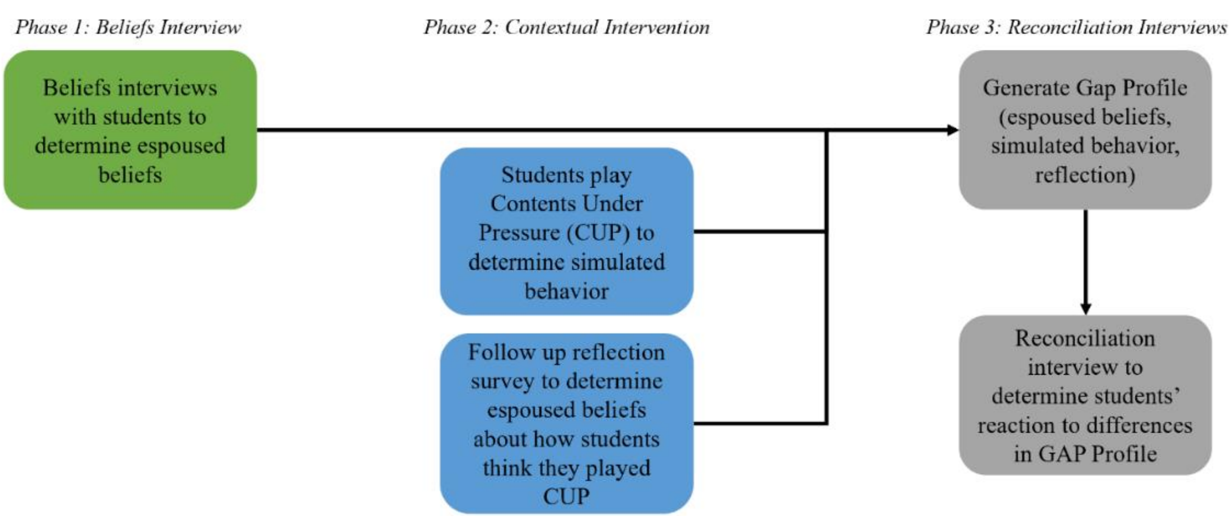

Fig. 1. Research Design Visualization (adapted from [34])

Phase 1: Beliefs Interviews

The first phase of this study involved conducting semi-structured interviews with students to determine their espoused beliefs when it comes to making process safety judgements. The interview was broken into two main sections: (1) students ranked the six criteria from the conceptual framework according to their beliefs about making process safety judgements, and

(2) students talked through five hypothetical, non-contextual scenarios and made judgements based on the information provided. For the criteria ranking, students were encouraged to perform the ranking however they wanted, which allowed for ties between criteria.

To analyze the data collected in this phase, two researchers independently developed analytic memos for each participant to outline the ways that students believe they would approach process safety judgements. Analytic memos are used as a way for researchers to summarize important information from data collection while providing personal interpretations and meaning [37]. After reflecting on student beliefs through analytic memos, the same two researchers used inductive thematic coding to identify themes and trends from the participant transcripts, reconciling any differences with a third researcher if no agreement could be reached [37], [38]. These themes and trends, related to students' beliefs about how they approach process safety judgements, were then supported by content from the individual's transcript obtained through this first order coding process [37]. Examples from the transcript were pulled from both the criteria ranking section and the hypothetical scenarios sections of the beliefs interview. Data collected in this phase was used to respond to research question 1.

Phase 2: Contextual Intervention

In the second phase of the study, students played through a digital game where their judgements determined their in-game criteria rankings. The game, Contents Under Pressure (CUP) [21], [39], is a tool to simulate process safety decisions in a chemical plant (Fig. 2). The player assumes the role of a chemical plant manager and is tasked with making judgements relating to various day-to-day plant operations. CUP follows a continuous 15-day narrative, where players make approximately 300 binary judgements over the course of the entire game. This includes revisiting the five hypothetical scenarios from the Phase 1 interview, now situated within the game context. Immediately following the completion of the game, students ranked the criteria via Qualtrics in a reflection survey to convey how they *believed* they behaved when making process safety judgements in the game. In this reflection survey, two criteria—leadership and relationships—were combined into a single criterion called "personal relationships" due to researcher error.

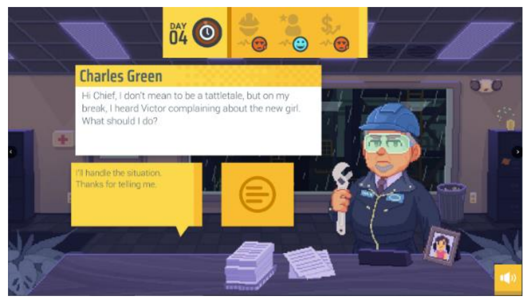

Fig. 2. Screenshot of CUP Gameplay

To analyze this data, researchers created a visualization to display student's criteria rankings collected at the three stages of data collection—espoused beliefs (beliefs interview), simulated behavior (gameplay), and espoused beliefs about behavior during gameplay (reflection survey). Criteria rankings from CUP are determined by quantifying the number of times players make judgements corresponding to specific criteria. Each students' criteria prioritizations in these three different stages of data collection are summarized through a GAP Profile (Table 3. GAP Profiles of Student Participants, in Results & Discussion).

Phase 3: Reconciliation Interview

The final stage of data collection for this study involves a second semi-structured interview with students. Again, this interview is broken into two distinct sections: (1) students compared various columns of their GAP Profile (e.g., espoused beliefs (beliefs interview) and their simulated behavior (gameplay)) and discussed their reactions to any differences they observed, and (2) students revisited their responses to the five hypothetical scenarios given during the beliefs interview in comparison to the responses the students gave in-game. These two sections of the interview allowed researchers to capture students' reactions to any differences that were captured in our analysis between their espoused beliefs (beliefs interview), behavior (gameplay), and espoused beliefs about behaviors during gameplay (reflection survey).

Again, two researchers independently utilized analytic memos to summarize each participant's interview transcript. The researchers then used inductive thematic coding to create a codebook of emergent themes [37], [38] related to the students' reflection process. This process entailed comparing their criteria rankings between espoused beliefs (interview), behavior (gameplay), and espoused beliefs about behaviors during gameplay (reflection survey), as well as the specific criteria juxtapositions that were presented in the hypothetical scenarios. Disagreements in codes were settled by a third researcher. A first order coding process was used to provide support for these themes from content identified in the student transcripts [37]. As in phase 1, the examples pulled from the transcript were taken both from the GAP Profile comparison section and the hypothetical scenario reflection of the interview. This process was used to answer research question 2.

Limitations

Limitations for this pilot study include the small sample size (n = 3) and recruitment from a single institution. Though trends in chemical engineering student responses did emerge because of this pilot study, the small sample size makes it difficult to definitively say they are shared characteristics of the studied population. Data collection occurred at a single university, failing to provide a perspective on chemical engineering students on a broader scale and thus limiting the transferability of these results. Future iterations of this project do plan to incorporate a larger sample population from other institutions to account for this limitation.

In the reflection survey in phase 2, two criteria—leadership and relationships—were accidentally combined into a single criterion called "personal relationships", which is inconsistent with the conceptual framework. This only had an impact on third column of the student's GAP Profiles and subsequently had limited impacts on the results shared as part of this study whereby the majority of discussion associated with the GAP Profile was focused upon differences between espoused beliefs (beliefs interview) and simulated behavior (gameplay). This error has been corrected for future iterations of the protocol.

Results & Discussion

This section will describe the results obtained for each of the research questions and how they are relevant to process safety education.

RQ 1: What are engineering students' beliefs about how they would approach process safety judgements with competing criteria?

To answer the first research question, three distinct themes were identified through analysis of the phase 1 beliefs interviews (Table 2).

Table 2. Codes of Participant Beliefs about Process Safety Judgements from Beliefs Interview

Students believed that they would approach process safety judgements...	**Definition**
By Focusing on Company Outcomes (n = 2)	Making judgements that primarily focus on the plant and company. Includes a motivation to remain loyal to company policy and expectations.
By Optimizing Criteria Based on Context (n = 2)	Making judgements that evoke an "optimal" outcome considering specific aspects of the context. Includes the introduction of hypothetical contextual factors.
By Remaining Unaffected by Relationships (n = 3)	Making judgements while remaining unaffected by relationships with others

Two study participants discussed the needs of the company to support their criteria rankings (Table 3, first column). These needs included financial considerations, like profitability and productiveness of manufacturing, as well as legal repercussions, such as completing safety reports and other paperwork. Both Alex and Bradley defended their criteria rankings using this approach. For example, when discussing the placement of the safety criterion in the beliefs interview, Alex stated that "*a plant can have a lot of drawbacks if they don't follow proper safety precautions that could affect the company as a whole or the entire chemical plant."* When discussing the placement of the production criterion, Bradley shared that *"people don't make chemical plants to make chemicals; people make chemical plants to make money."* Productivity of the company influenced other criteria rankings made by Bradley, who stated that *"I do think the leadership would have big role in making sure the plant is staying productive."* Both Alex and Bradley emphasized the importance of each criterion based on their idea of the company's perspective to better support their criteria rankings. Students' espoused beliefs may be limited to any practical experiences they have in industry (if any) or may be solely grounded in classroom theory [13], [28]. Therefore, Alex and Bradley may be defaulting to a set of company values that they anticipate a future workplace holding.

Table 3. GAP Profiles of Student Participants

Alex	**Ranking**	**Column 1 Espoused Beliefs (Beliefs Interview)**	**Column 2 Simulated Behaviors (CUP)**	**Column 3 Reflection (Survey)**
	1	safety	safety	safety
	2	production	leadership	production
	3	leadership	production	spending
	4	time	relationships	time
	5	spending	spending	"personal relationships"
	6	relationships	time	

Bradley	Ranking	Column 1 Espoused Beliefs (Beliefs Interview)	Column 2 Simulated Behaviors (CUP)	Column 3 Reflection (Survey)
	1	leadership	relationships	safety
	2	safety	production	“personal relationships”
	3	production/spending	leadership	spending
	4	relationships/time	safety	production
	5		spending	time
	6		time	
Charlie	**Ranking**	**Column 1 Espoused Beliefs (Beliefs Interview)**	**Column 2 Simulated Behaviors (CUP)**	**Column 3 Reflection (Survey)**
	1	safety	safety	safety
	2	leadership	spending	“personal relationships”
	3	relationships	leadership	spending
	4	production/spending	production	production
	5	time	relationships	time
	6		time	

Two participants were unsure of how to prioritize a single criterion in hypothetical scenarios; both Bradley and Charlie negotiated specific criteria juxtapositions to find a more optimal way forward. In the first hypothetical scenario in the beliefs interview, students were asked to decide to either personally help an employee asking for help about filling out a time sheet (Leadership), or to delegate this task to another employee (Time) (Appendix A, question 2). In this scenario, Bradley felt limited by responding with a single criterion, *“[I] wish there may have been a C option.”* This was a sentiment that Bradley continued to comment on through the continuation of the interview, remarking that sometimes the response would be different based on the context of the situation, *“I would assume some of these... it- it doesn't say like [option] A doesn't say… but there'd be some factors that depend, you know whether you have more context or not.”* Charlie felt similarly, but instead of expressing frustration directly, they would provide their own context to the situation. When faced with a hypothetical scenario addressing a steam leak that has occurred in the plant (Appendix A, question 6), Charlie talked through the scenario thoroughly, and provided their own context to justify their final answer, *“you can focus on storm* *preparation, you can set one or two operators and engineers aside to fix one valve, not that big a deal."* Throughout the entire interview, Charlie claimed that certain criteria could influence others, suggesting that the criteria cannot stand alone when making judgements, *"how safe you're going to make something is going to… affect everything going down," "production and spending are always going to go hand in hand,"* and *"I mean all these things kind of interconnect in some ways."* Bradley and Charlie's reliance on negotiating outcomes in complicated situations is reflected in other studies investigating how chemical engineering students approach process safety judgements. One study showed that in student responses to process safety judgements, many participants had trouble navigating the complexity of certain situations, sometimes even proposing alternative solutions to search for a more optimal outcome [40]. The choices presented in CUP are binary, so it is also possible that the students in this pilot study were frustrated with how the responses were worded, prompting them to negotiate the scenario to optimize the outcome.

All participants responded to scenarios which involved relationships and conflicts with others by remaining unaffected by the relationship, however, the students mentioned these situations were more difficult for them. When presented with a judgement involving an injured employee (Appendix A, question 4), Alex felt the situation was *"a bit more difficult…to make a judgement call on"*. Charlie echoed this concern for this same scenario, stating *"yeah this one feels more difficult, obviously, because it's like a direct incident like someone actually was hospitalized and obviously badly injured."* While Bradley initially stuck to their company-focused mindset and chose to follow protocol for the same situation, they acknowledged the responsibility they would need to shoulder for the incident and created more context to help them discuss their choice, *"I feel that the protocol their report… I would assume some of these... it- it doesn't say… [but]by following the proper procedure, maybe after she's all better, there are certain trainings we could do with her and then she can get familiar with the equipment. I'd still feel bad that she got burned."* Additionally, Bradley and Alex's rankings reflected relationships being the least important consideration for them when considering their approach to process safety judgements (Table 3, column 1). This could suggest that the participants' initial approach to making judgements were being challenged by intricacies related to the relationships criterion that they were not expecting to arise in the context of chemical process safety related judgements. An alternative explanation could be emotional connections to others serving as a mechanism for creating feelings of doubt about the relationship criterion [41]. This suggests that the participants might feel insecure about the way their emotions played into their judgements and could consider this "incorrect" in the context of a chemical plant. The impacts of human factors in process safety judgements are understudied [42], though chemical process safety incident reports have shown that relationships can prevent professionals from prioritizing safety in fear of catching "flack" from other employees, resulting in riskier behavior [8]. Risky behavior tends to occur when emotions cloud our ability to think clearly about our decision-making approach [41], [43], suggesting that the emotional component that comes with relationships with other people might make students behave in ways that may conflict with their self-determined criteria priorities.

RQ 2: How do students react to the process of comparing their beliefs and behaviors in process safety judgements?

To respond to research question 2, three key themes were identified that reflected students' reactions to comparing the differences between their espoused beliefs (interview), behavior (gameplay), and espoused beliefs about behavior (reflection survey) (Table 4).

Table 4. Codes of Participant's Reactions to Differences Between Beliefs, Behavior and Espoused Beliefs about Behavior

Students react to differences in their beliefs and behaviors by…	Definition
Conveying an Increased Awareness of how Relationships Factor into their Judgements (n = 3)	Expressing consideration of relationships in process safety judgements.
Committing to their Behaviors Over their Beliefs (n = 2)	Stating that one's espoused beliefs are not reflective of performed behaviors.
Conveying the Impact of Context and Feedback on their Judgements (n = 3)	Recognizing that judgements are influenced by context and feedback.

When reacting to the differences between espoused beliefs and behaviors, students expressed an increased awareness of how relationships factored into their process safety judgements. In the beliefs interview, all three participants had trouble navigating the relationships criterion. Initially, Alex and Bradley ranked relationships as one of the least important factors when making process safety judgements (Table 3, column 1), however, both participants noted the importance of relationships after completing CUP. Alex stated at the end of the reconciliation interviews that they *"think that a lot more things are based on relationships or like everyday scenarios are based on relationships, and building those strong relationships could make it a lot easier working in the future."* When revisiting a hypothetical scenario that involved a character asking for an extension on a report (Appendix B, question 7), Bradley reflected on the connections they made to specific characters in the game, noting the quality of that relationship drove the direction of some of their choices, *"the characters in which that were always more like dragging their feet, like the character you probably named like Victor… Sometimes when he asked for extra stuff or time, you know- he'd be a 'constant repeater' of it."* Charlie was consistent in their understanding of relationships, continuing to heavily prioritize both personal and workplace relationships in their justifications, *"positive relationships, having a good work-life balance, just leads to an overall better experience."* Though there was a stated growth in understanding of how relationships may create a bias or additional challenge in making judgements, Alex and Charlie continued to struggle with applying it to specific situations. Alex's ranking for relationships in the reflection survey remained last, suggesting that although they acknowledge they play an important role in making judgements, they still would not prioritize relationships over other criteria (Table 3, column 3). Charlie's indecisiveness when facing a scenario involving an injured worker continued into the reconciliation phase, however, this time choosing to rely on the needs of the company to act as a moral compass in this situation, *"I mean, obviously I want… to give as much time as she needs, but you got to keep the plant on its feet… [I] think the right decision is to follow protocol."*

The experience chemical engineering students have with making process safety judgements as undergraduates is often limited due to age or prior experiences within the field. Typically, students do not have the ability to practice managing the intricacies of such judgements, potentially leaving gaps in their knowledge of which they are unaware [15], [23] leading to potentially riskier behavior [41], [43]. In this study, the participants were able to react to the differences in their beliefs and behaviors, allowing them to build awareness around their own beliefs about their judgements. This awareness is foundational to avoiding poor judgements in the future [15]. All three students displayed a better recognition of the relationship criterion, indicating that their understanding of the impact of this criterion in context may have been limited before gameplay. Another study showed that personal relationships can be highly influential to the ethical decision-making process – additional complexity being added by the nature of relationship and the traits that are associated with it [44]. Though participants may not have fully explored how the nuances of personal relationships influence all process safety judgements, they have at least had the opportunity to confront this discomfort in context, hopefully bringing awareness to any potential future decisions.

Though participants had two opportunities to state their espoused beliefs about how they approach process safety judgements (beliefs interview, phase 1 and reflection survey, phase 2), two participants felt as though their simulated behaviors in CUP were more representative of how they would make judgements. We asked the participants to determine which set of rankings displayed in the GAP Profile they felt was most representative of them (that is, their priorities expressed during the initial interview or through judgements during CUP gameplay). Alex and Bradley both described that their gameplay rankings were the most accurate. Alex stated that *"honestly, I'd fall more into my actions with criteria during the game,"* and Bradley felt like their gameplay rankings were *"more representative of what [they] did."* Both students acknowledged that there were significant changes between their beliefs and behaviors, but ultimately determined that their gameplay decisions were better predictors of future behaviors. Charlie never determined a ranking which was ideal for them, ultimately expressing that in the game, *"I was trying to optimize everything."* This suggests that Charlie may have had difficulty consistently determining an ideal ranking of the criteria. Alex and Bradley vocalized that their in-game judgements were most representative of their actual criteria priorities when facing process safety judgements. The phase 3 reconciliation interview exists to provide students with the experience of reconciling stated beliefs with performed behaviors. Perhaps Alex and Bradley now feel as though their espoused beliefs are better informed by their simulated behaviors (from gameplay), hopefully limiting the existence of any gaps in awareness in the future [15].

Though the content discussed in the beliefs interviews was provided without context, all the participants felt that their judgements in CUP were heavily influenced by the context provided in the game. Bradley determined their success in the game by avoiding critical failures, *"I never had one of those failures in the game with the safety thing. I always kept that like circle icon like, I'd say happy."* Alex stated that both the relationships and time criteria were more difficult to manage than they initially anticipated, stating that *"it was definitely a lot harder than I thought to keep everyone happy with each other. I think that the game did a great job showing that there is a lot of butting heads that can be done in a real life scenario,"* and *"a lot of the decisions that I thought I was making for the process I ended up having to do in the…rush that they had in the* *game, when everything starts flashing red and it was the decision of you've gone over time."* Though expressing frustration with balancing relationships in the game, Alex showed awareness for the importance of this criterion in reflection. Charlie attempted to strike a balance between all the criteria in CUP by comparing the value of the on-screen metrics, "*if my production is down what decision's going to bring it up, even if it might lower something else… like I have really good relationships right now, but my productions almost… in the red. I can bring up and they [can] both be in the yellow, but definitely, that's better than a failure."* The idea of being reliant on experience was continually noted by all participants, as all three shared that the visual-written feedback provided by the game metrics and characters was influential on their in-game judgements. Social learning theory describes social learning as a process through which observation and behavior are critical in determining the future actions of an individual [45]. This phenomenon may have contributed to this observed result. This could indicate that students were using CUP to experiment with balancing different metrics and working to understand how these different criteria interact with each other. Perhaps the feedback provided by the game served as a way for students to gauge their priorities situation to situation. The reliance on gameplay feedback further suggests that continual feedback and experience is a crucial step to developing beliefs around competing criteria in a process safety context.

Conclusions

Though resources for hazard mitigation and safety regulations exist in chemical process safety training, situations where criteria compete for attention from the decision-maker continue to evade these taught skills. Due to the physical limitations of a classroom, it can be hard to incorporate opportunities to confront these types of judgements in education [23]. The goals of this study included using a game-based learning approach to help students navigate situations in a process safety context which have competing criteria and compare their in-game behaviors to previously recorded espoused beliefs. Research suggests that having students confront the differences that may exist between their espoused beliefs and their behaviors may lead to more awareness in these types of situations in the future, mitigating potential poor choices [15]. By evaluating the criteria priorities of each student from the conceptual framework, we were able to compare chemical engineering students' espoused beliefs and performed behaviors in the context of making judgements in the chemical process industry.

The results of this pilot study suggest that senior chemical engineering students gained awareness of the differences that may exist between their espoused beliefs and behaviors when making difficult judgements. Notable results include the awareness that students were able to gain about certain criteria, such as relationships. Other studies suggest that personal relationships can have influences on judgements [23], [44], and by playing through Contents Under Pressure (CUP) participants were able to understand the specific nuances these can have on process safety judgements. As incidents in the chemical process industry continue to occur due to these competing criteria [5]–[9], [16], teaching tools like CUP could help students experiment with the interactions of these factors. The finding that students felt like the feedback of the game helped with making judgements suggests that experience and context are central to the development of our espoused beliefs [28]. Though there have been efforts to improve process safety education in classrooms, these processes lack the ability to help students gain awareness to working with these criteria in specific situations. This lack of experience could lead to students having beliefs that are oversimplified or uninformed. Hopefully, the experience of confronting potential differences between espoused beliefs and simulated behavior will provide students with the awareness they need to mitigate future process safety incidents with competing criteria.

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Appendix A – Beliefs Interview Protocol

Date: ______________________________

Time: ______________________________

Interviewer: ________________________

Pseudonym: _______________________

Protocol Introduction

Questions to build rapport:

- How did you come to where you are as an engineering student now?
- Have you thought much about where you would like to go next with your career?

Background for the context: The purpose of this conversation is to help us as researchers understand how engineering students / engineers, like yourself, make decisions and judgements related to process safety. We just want to talk about your beliefs, opinions, and experiences when it comes to making judgements. And when we say judgements, we're talking about real-world judgement calls where there isn't a textbook right or wrong answer. We want you to describe whatever *your* perspective makes you think or feel, and how that leads you to react. This study is an exploration, so there really isn't a right or wrong answer. Do you have any questions before we get into it? [*wait for response*]. When engineers make judgements, they often need to make tradeoffs between things they find valuable…

Initial Rankings

We have six criteria that often come into play when engineers are faced with real-world decisions in the context of process safety. I want to share what we mean by each term--some examples for all six are here on this screen share. I can read these aloud to you, or you can read them to yourself, whatever you're most comfortable with. [*pause for participant to go over these while sharing them on screen*]

A. Leadership: how you manage employees and your reputation as a supervisor. Authority, mentorship, credibility.
B. Production: the bottom line that your company or employer wants you to meet, output from the plant facility. Getting things done.
C. Relationships: how your coworkers see you as a person and the way in which you may care for them and other important people in your life, such as your family. Connections with people.
D. Safety: preventing injuries to people/plant machinery or environmental effects that may occur from chemical leaks that get into the air or waterways.
E. Spending: sticking to company budgets and reducing expenses
F. Time: your availability to spend time with family, participate in hobbies, and invest in your career.

Can I clarify any of these terms for you. Is anything confusing?

We want to understand how you believe these six criteria rank relative to one another in terms of how important they are to you and your process safety judgements. To help us talk this through, we are going to click-and-drag these icons to the slider on the screen to rank them in an order of importance that makes the most sense to you. [*use sub-bullets as appropriate:*]

- Which criteria would you like to start with?
- Okay, is this okay in the line up?
- Which criteria would you like to rank next?

1. Okay, now let's talk through your list. Why did you rank each item where you did? Feel free to justify your ranking with anything you've experienced in school, work, or wherever that informed your ranking. [*employ follow ups as appropriate:*]
   - ______ looks to be the most important criterion to you. Why is that?
   - These criteria seem to be tied in importance. Can you talk about why you believe they are equally important?
   - It appears that ______ is the least important criterion to you. Why is that?
   - So what I am hearing is that ______. Is that correct?
   - So you think ____ is more important than _____ and _____? Is that right? Why do you think that?
   - If trying to balance any criteria instead of ranking in a hierarchy, please explain why you want to **balance** certain things.
   - Are there any situations or contexts where you might change your rankings? Why?
   - [Let them lead trying to pick hierarchies, but if they are looking to balance some criteria, invite them to balance them].
   - Let me check my notes, and see if there is anything else I want to follow up on…

<u>Hypothetical Scenarios</u>

For this next part of the interview, we want to walk you through a couple of hypothetical scenarios. I can read them to you or you can read them aloud or to yourself. Whatever you are most comfortable with. After reading them, we are going to ask how you would respond to the scenario. Do you have any questions? [*wait for response*]

So the context for each of these scenarios is that you are a chemical plant manager. You are in charge of making the decision in these scenarios. The first scenario is this [s*how via screen share*].

2. *[Leadership and Time:]* You are in your office towards the end of the day working to complete your tasks before heading home, and one of your employees knocks on your office door. You tell them to come in, and the employee says, "Hi again! Can you explain to me how overtime works? Charles told me to prepare an overtime sheet for next week." Your options are to respond with "I can show you. I'm closing out the day by reviewing them." [*leadership*] or "If Charles told you to do it you can ask him for help." [*time*] Which would you choose and why?
   - How did you come to that decision?
   - Is there anything that might change your mind about your decision?

- What influenced you to make that decision? If ‘that’ changed, how would you make the decision?
- So what I am hearing is that _______… Is that correct?

3. [*Relationships and time:*] You are in your new manager’s office for a position you recently accepted, and you are approached by one of your engineers. They say, “Hey Chief, would you like to get lunch with me? I thought it would be great to get to know you better.” Your options are to respond with “I'm sorry, I have no time today.” [*time*] or “Yes, that sounds great! I'll be ready shortly.” [*relationship*] Which would you choose and why?

4. [*Leadership and Relationships:*] A recent storm stretched your team thin, so you had to assign an employee to work on some equipment they were unfamiliar with. They were badly burned and hospitalized. The head chief of the plant pulls you aside and says, “Hey, I just heard about Emily. That was on your watch. How are you dealing with it?” Your options are to respond with “By following protocol. There are reports I have to account for.” [*leadership*] or “I'm giving her as much time as she needs. We can't afford to lose her.” [*relationships*]. Which would you choose and why?
    - [*Add context as they need it here:*] The engineer who previously held your position was relieved because of poor safety protocol.
    - [*Add context as they need it here:*] The engineer who was hurt was a new employee who filled a critical vacant role.

5. [*Leadership and Production:*] An engineer who you recently assigned to write a production report pops into your office, and says, “Hey, bad news. I don't think I'll be able to finish this report by today. Can you give me an extension?” Your options are to respond with “Yes, try and get it done by tomorrow at the end of the day.” [*Leadership*] or “No, this was a strict deadline. I need you to stay late and finish it.” [*Productivity*] Which would you choose and why?
    - [*Add context as they need it here:*] This report is for your boss, and you cannot submit it until the other engineer completes their entry. The entire report is due at the end of the day tomorrow.

6. [*Production and Safety:*] You are making preparations for a dangerous hurricane to make landfall over the plant you manage. One of your engineers pulls you aside and exclaims, “What's this about a valve leak? Should I do this or should I make storm preparation my priority?” Your options are to respond with “Don't worry about Darwin's leak. Just focus on storm preparation. [*production*] or “Fix it today, Darwin has a direct line to the head chief.” [*safety*] Which would you choose and why?

A. [*Add context as they need it here:*] This is a steam leak that is not releasing chemicals.
B. [*Add context as they need it here:*] So far, no one has made preparations for the storm.
C. [*Add context as they need it here:*] Darwin is the safety supervisor who already said the valve leak needs repaired.

<u>Revisiting Rankings</u>

7. Okay, now that we have gone through those scenarios, I want to loop back to your rankings of the criteria. [*copy the rankings from the first slide to the seventh slide*]. Have you changed any of your thoughts on these rankings? [*employ follow ups as appropriate:*]

- ______ looks to be the most important criterion to you. Why is that?
- These criteria seem to be tied in importance. Can you talk about why you believe they are equally important?
- It appears that ______ is the least important criterion to you. Why is that?
- So what I am hearing is that ______. Is that correct?
- So you think ____ is more important than _____ and _____? Is that right?
- If trying to balance criteria instead of ranking in a hierarchy, please explain why you want to **balance** certain things.
- Are there any situations or contexts where you might change your rankings? Why?
- [*Let them lead trying to pick hierarchies, but if they are looking to balance some criteria, invite them to balance them*].
- Let me check my notes, and see if there is anything else I want to follow up on…

Is there anything else you want to add, or you think we missed or didn't get to cover?

Okay, NAME, thank you so much for agreeing to be a part of this interview. In the coming weeks, you will have the opportunity to engage with Contents Under Pressure as part of your class deliverables. While playing Contents Under Pressure, make sure you sign up using your pseudonym from this interview. After that, we will have a follow up interview to discuss your experiences. Do you have any remaining questions?
[goodbye].

Appendix B – Reconciliation Interview Protocol

Date: ______________________________

Time: ______________________________

Interviewer: ________________________

Pseudonym: ________________________

<u>Protocol Introduction</u>

Thank you for participating in these interviews. We are looking to follow up with you now that you've completed your playthrough of Contents Under Pressure in class, as we want to understand how you made decisions within the context of the game. Just like the first interview you did, we want you to talk candidly about your beliefs and opinions, and we want to emphasize that there is no right or wrong answer here. We will be comparing your responses from before, during, and after you participated in Contents Under Pressure, and we hope that you will reflect on your ranking of criteria in each of those settings.

Do you have any questions before we begin? [*wait for response*]

<u>Ranking Comparison</u>

[*screen share: show criteria definitions*] As you may recall from our first interview, we asked you to rank these 6 criteria in order of how important they are to you when it comes to making process safety decisions. We have them on the screen so you can re-familiarize yourself with the criteria and their definitions, you can read them to yourself, or we can read them aloud. [*wait until they are done reading*]

A. Leadership: how you manage employees and your reputation as a supervisor. Authority, mentorship, credibility.
B. Production: the bottom line that your company or employer wants you to meet, output from the plant facility. Getting things done.
C. Relationships: how your coworkers see you as a person and the way in which you may care for them and other important people in your life, such as your family. Connections with people.
D. Safety: preventing injuries to people/plant machinery or environmental effects that may occur from chemical leaks that get into the air or waterways.
E. Spending: sticking to company budgets and reducing expenses
F. Time: your availability to spend time with family, participate in hobbies, and invest in your career.

Do you have any questions about these criteria or definitions before we move on? [*wait for response*].

1. So, during our last interview, we had you rank these criteria on this slider to express your perspective about how you would prioritize the criteria when making process safety decisions. For our research, we want to compare what people believe they will do to the decisions they actually make when they play Contents Under Pressure. From our first interview, you might recall you had organized your criteria in this slider [*show ranking slider from interview 1*]. In this column, we have your ranking from the first interview and the ranking we found based on your decisions in the game. [*show GAP column 1&2*]. I will give you a second to review this, and then we can discuss.

    - What do you notice when you compare the two columns? Why do you think that is? Anything else? [*probe as necessary*]
    - Initially, you had ranked *XXX* higher than *YYY*, but during CUP your rankings reflected *ZZZ*. What do you think influenced you to prioritize this criteria more?
    - Were there any interactions with the characters that made making decisions more difficult for you? If so, which ones?

2. Let's change gears a bit. Our research is also interested in exploring patterns between the decisions made when playing the game and beliefs about how those decisions were made. So we'll keep looking at this second column representing the actual decisions you made in Contents Under Pressure, but now let me show you a new column--this is the way that you ranked the criteria when you completed the game and how you believed you you prioritized things when you played the game when you reflected afterwards in the survey. [*show GAP column 2&3*].

    - What do you notice when you compare these two columns? Why do you think that is? Anything else? [*probe as necessary*]
    - In the game, you prioritized *XXX* over *YYY*, but you believed otherwise, how do you explain this difference?
    - What led you to believe that you were prioritizing *XXX* during gameplay?

3. We now want you to consider all three columns at the same time…your beliefs from the first interview about how you would prioritize the criteria, the way you prioritized during the game play, and your beliefs about how you prioritized during the game play right after you finished playing. [*show GAP columns 1,2,&3*].

    - What do you notice when you compare across the entire table? Why do you think that is? Anything else? [*probe as necessary*] Do you see any patterns?
    - Given our discussion today, how do you think this will affect your process safety decision-making processes moving forward?
    - [*Add specific question prompts to each interview based on their data and trends*].

Is there anything else you would like to review or discuss about these rankings before we move on? [*wait for response*].

Situational Comparisons

As you may recall from your first interview, we walked through 5 hypothetical scenarios where you took on the role of a chemical plant manager to make decisions. We want to compare the answers you provided in the interview with the decisions you made in those same scenarios in CUP. We'll walk through all five individually again and remind you of the choices you made. [*show scenarios via screen share*].

4. *[Leadership and Time:]* You are in your office towards the end of the day working to complete your tasks before heading home, and one of your employees knocks on your office door. You tell them to come in, and the employee says, "Hi again! Can you explain to me how overtime works? Charles told me to prepare an overtime sheet for next week." Your options are to respond with "I can show you. I'm closing out the day by reviewing them." [*leadership*] or "If Charles told you to do it you can ask him for help." [*time*]

   Initial _______ CUP____________

5. [*Relationships and time:*] You are in your new manager's office for a position you recently accepted, and you are approached by one of your engineers. They say, "Hey Chief, would you like to get lunch with me? I thought it would be great to get to know you better." Your options are to respond with "I'm sorry, I have no time today." [*time*] or "Yes, that sounds great! I'll be ready shortly." [*relationship*] Which would you choose and why?

   Initial _______ CUP____________

6. [*Leadership and Relationships:*] A recent storm stretched your team thin, so you had to assign an employee to work on some equipment they were unfamiliar with. They were badly burned and hospitalized. The head chief of the plant pulls you aside and says, "Hey, I just heard about Emily. That was on your watch. How are you dealing with it?" Your options are to respond with "By following protocol. There are reports I have to account for." [*leadership*] or "I'm giving her as much time as she needs. We can't afford to lose her." [*relationships*]. Which would you choose and why? [Prioritize this juxtaposition]

   Initial _______ CUP____________

7. [*Leadership and Production:*] An engineer who you recently assigned to write a production report pops into your office, and says, "Hey, bad news. I don't think I'll be able to finish this report by today. Can you give me an extension?" Your options are to respond with "Yes, try and get it done by tomorrow at the end of the day." [*Leadership*] or "No, this was a strict deadline. I need you to stay late and finish it." [*Productivity*] Which would you choose and why? [Prioritize this juxtaposition]

   Initial _______ CUP____________

8. [*Production and Safety:*] You are making preparations for a dangerous hurricane to make landfall over the plant you manage. One of your engineers pulls you aside and exclaims, "What's this about a valve leak? Should I do this or should I make storm preparation my priority?" Your options are to respond with "Don't worry about Darwin's leak. Just focus on storm preparation. [*production*] or "Fix it today, Darwin has a direct line to the head chief." [*safety*] Which would you choose and why? [Prioritize this juxtaposition]

   Initial _______ CUP____________

Have you finished re-familiarizing yourself with this decision? [*wait for response*] [*have them re-familiarize themselves with each situation before showing them their believed decision, CUP decision, and average criteria ranking*].

This prompt posed [*criteria 1*] against [*criteria 2*]. So when we interviewed the first time, you said in-general/ideally/in-most-cases, that you would react with ___A/B___, to _____action______. [*Fade in their decision*] When you played through Contents Under Pressure, you (actually/also) said ___A/B___, to _____action______.

- Do you recall why you made this decision in the game?
- What do you think this means about making decisions with these criteria in the future?
- Does this pattern of prioritizing criteria make sense to you? Do you find this surprising based on your experience? Why or why not?
- Do you think this is accurate? Or that this data represents you?

So, we only showed you one decision from the game. This comparison between [criteria 1] and [criteria 2] was presented to you **X** number of times in the game; we found the percentage of time you prioritized each shown in this figure. [*display divided gradient slider on screen*].

- Do you think this is a better representation of your decisions?
- How well do you think this lines up with your beliefs from the first interview?
- Do these results surprise you?
- Do these results feel like they align with your priorities?
- Do you think playing the game changed your desired outcome for these criteria? Why or why not?

Okay, NAME, thank you so much for agreeing to be a part of this study. Your participation is greatly appreciated. If you ever want a copy of your results to reference in the future, feel free to reach out to us after the conclusion of this interview. If you have any questions or concerns in the coming weeks don't hesitate to reach out. Do you have any questions for us now? The PI for this study will be in touch regarding compensation.