Navigating the Theory-to-Practice Gap: Insights from a Process Safety Education Pilot Study

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Background and Motivation

Students transitioning from their undergraduate engineering degrees to their first full-time industry roles find themselves faced with what is commonly known as the Theory-to-Practice gap [1], [2]. While new engineers believe their roles in industry will consist of direct application of the theories they learned in school, they are instead faced with the need to build professional skills such as communication, coordination, and leadership [3]. The Theory-to-Practice gap represents this divide between the theoretical concepts taught in academia and the practical knowledge required in industry. This gap results in an induction period for engineering students where they need to understand their new environment and become independent contributors to their workplace [4]. The Theory-to-Practice gap has been identified to be the result of many factors, from academic funding to pedagogies, or even just the lack of time students have to master complex engineering topics like process control [4]. Rhinehart [4] states that academic funding and institutional hiring are based on generating research, which can result in limited industrial experience among engineering faculty that may also contribute to the gap. Rhinehart [4] also suggests that four years is not enough time to teach engineering students all the skills they will need to know before entering industry, and rather they should be equipped with the ability to develop life-long learning skills that will allow them to gain the knowledge and skills required for their careers.

The Theory-to-Practice gap is being studied in a variety of engineering areas, such as software engineering, computer science, and graduate-level engineering courses [5]-[8]. However, little to no research has been done to study the Theory-to-Practice gap in process safety. This study will focus on the Theory-to-Practice gap in the field of process safety, specifically on process safety judgments. Poor engineering judgment in process safety contexts has been shown to have substantial impacts on the immediate employee, the company, and the surrounding community and environment [9]. For this reason, it is imperative that students choosing to enter the process safety field after graduation have a minimal induction period. This study will generate new knowledge on how students and practitioners approach process safety judgments that ultimately supports the difference in expertise between students and practitioners in the process safety realm. Levels of expertise of both students and practitioners will be dictated by the Dreyfus model of skills acquisition [10], which is explained in a later section of this paper.

Process Safety

Managing process safety is a crucial aspect to any company operating with highly hazardous chemicals. Despite the emphasis placed on process safety management in both industry and academia, process safety incidents continue to occur [9]. Process safety incidents can occur for many reasons, however, many of these reasons point back to human factors, such as a poor safety culture, lack of training, or outright mistakes [11]-[13]. The Chemical Safety Board (CSB) investigation of the BP Texas City refinery explosion and fire identified human factors as a key issue, as the work environment promoted deviation from the written procedures, and there was a lack of training regarding abnormal and start-up conditions [11]. Similarly, the CSB identified that a lack of training for operators and operator fatigue were factors that led to the chemical runaway reaction at Bayer CropScience [12]. Baybutt [14] says that important considerations in process safety judgments can be overlooked due to human factors such as emotion or reputation. It is possible that the human errors that lead to these process safety incidents are a manifestation of the Theory-to-Practice gap, but more research is needed.

For these reasons, it is crucial to identify students' expertise of process safety concepts upon completing higher education. By understanding the contexts that influence students process safety judgements versus the contexts being applied to process safety judgements in industry, we can determine if the Theory-to-Practice gap is occurring in process safety education. The Dreyfus Five-Stage Model of Adult Skills Acquisition [10] offers a method for evaluating engineering students' understanding and application of skills. The skills acquisition model has been widely applied in professional and academic contexts for

training, education, and leadership [15]-[17]. Using the Dreyfus Five-Stage Model of Skills Acquisition could be beneficial in identifying engineering students' level of expertise in process safety upon graduation.

Dreyfus Five-Stage Model of Skills Acquisition

Dreyfus & Dreyfus' [18] original model of skills acquisition was a result of an ethnographic study that observed the changes in perceptions of individuals as they developed complex skills. The original model divided this process into five stages: novice, competence, proficiency, expertise, and master, later revised to novice, advanced beginner, competent, proficient, and expert [10]. An individual is classified into one of the five stages based on how they perform in four categories: components, perspective, decision, and commitment. Components define the elements of the situation the individual can recognize and can either be context-free or situational [10]. As the individual begins to recognize how different contexts can impact their decision, their perspective begins to change. Perspective progresses from none in early stages, to chosen perspectives, and finally experienced perspectives in later stages [10]. Decisions can either be analytic or rule-based, which is common up until the expert stage when decisions become intuitive [10]. Commitment describes an individual's immersion and emotional involvement surrounding the components of the situation [10].

Individuals' judgment and intuitive decision-making capabilities strengthen as they progress through the stages of skills acquisition. Novices apply uniform rules without context, making analytical decisions with no emotional attachment [10]. Advanced beginners make analytic decisions but recognize situational context that may influence their responses [10]. Individuals at the competent level become involved in outcomes, experiencing euphoria or remorse based on the result of their response, and begin to confidently question given instructions [10]. At the proficient level, individuals loosely follow rules, leaning towards intuition based on experience [10] to guide their judgments and decision-making. Experts primarily rely on intuition, rarely resort to rules, and are fully immersed in the understanding, decision-making, and outcomes of a given scenario [10]. A summary of the progression from novice to expert through the four categories of skills acquisition is provided in Table 1.

Table 1. Progression of Dreyfus skills acquisition levels [10].

Stage	Components	Perspective	Decisions	Commitment
Novice	Context-free	None	Analytic	Detached
Advanced Beginner	Context-free, minor situational context	None	Analytic	Detached
Competent	Context-free and situational	Chosen	Analytic	Involved in outcome
Proficient	Context-free, mostly situational	Experienced	Analytic, some intuitive	Involved in outcome and understanding
Expert	Almost always situational	Experienced	Intuitive	Involved in outcome, understanding, and deciding

Undergraduate chemical engineering students are likely to operate at the novice or advanced beginner level in the context of process safety due to limited exposure, lack of contextual understanding, and reliance on rule-based problem-solving [4], [19]. Learning complex engineering concepts in a sterile environment and solving textbook problems with prescribed methods contribute to analytic, rule-based judgments typical of early skill acquisition stages. Gaining experience is essential to progressing through the skills acquisition levels, which typically results in lower-level placement for students [10], [20]. Prior experience will dictate the perspective an individual has when approaching a problem; those with no experience will not have enough information to have a chosen perspective and will rely on the rules

available to them [10]. Experience enhances perspective, shifting from rule reliance to a chosen perspective, promoting less analytic and more intuitive judgments [10]. However, undergraduate engineering students lack sufficient experience to develop engineering intuition independently [21]-[23]. The level of students' involvement in their judgments influences their skill acquisition, with a crucial distinction between the advanced beginner and competent phases being emotional engagement with outcomes [10]. Individuals who gain a sense of responsibility for their actions and have an emotional response to the outcome of their judgments will move out of the advanced beginner phase, and into the competent phase [10]. Those who are unable to become involved in the understanding, decisions, and outcomes of their judgments are less likely to advance their skills acquisition [15], [20]. Students may struggle to become involved due to the lack of exercises that have real-world implications [24], posing a significant obstacle to advancing to later skill acquisition stages.

In contrast, industry professionals with experience in the process safety field are likely to operate at proficient or expert levels when making process safety judgments. Experience is the driving factor behind the process of skills acquisition, as it exposes an individual to situational context that would inform better judgments [10], [20]. As an individual gains experience, their perspective moves from a "chosen" perspective to an experienced perspective [14]. Experience also leads to the development of intuition, which is an expert trait [10], [21]-[23], [25]. This is shown in a study by Mohedas *et al.* [17] who found that individuals conducting interviews and determining design ethnography at the proficient or expert level were operating solely off experience and intuition.

In this study, we interviewed experienced industry professionals in the process safety field to determine their approaches to process safety judgments. We then compared these findings to results from two previous student studies where the same study design was used [26], [27] that determined how senior undergraduate chemical engineering students approach process safety judgments. By analyzing participant responses to hypothetical process safety scenarios, we were able to identify several key differences in their approaches to process safety judgments. Both the students' and practitioners' approaches to process safety judgments informed their levels of expertise which may indicate the Theory-to-Practice gap within process safety. This study was guided by the following two research questions:

RQ 1: What do industry practitioners believe about how they will approach process safety judgements?

RQ2: What differences exist, if any, between how industry professionals' and undergraduate engineering students' believe they will approach process safety judgments?

Methods

This industry professional pilot study followed the same methods from two earlier studies conducted with senior chemical engineering students [26], [27]. The first student study was a pilot study conducted with three senior chemical engineering students from a single, large, MidAtlantic institution where students were enrolled in a senior level process safety course [26]. The student pilot study was later replicated as a large-scale student study with 14 senior chemical engineering students taking a senior design course that included process safety content at a large South Atlantic institution [27].

Study Design

Three industry professionals participated in this pilot study. Industry professionals were recruited through internal connections within the research team and were asked to complete an interest form and consent form before participation. Data obtained from the participants was de-identified, and participants were assigned pseudonyms (Bingo, Craft, and Domino). Participants then completed a three-phase research study during the Summer of 2023. IRB approval was obtained prior to data collection and analysis.

The semi-structured beliefs interview involved two sections, and follows the same protocol as the two earlier student studies [26], [27]. The protocol for this interview can be found in Appendix A. In the first section of the interview, participants were asked to rank six criteria from a conceptual framework which identifies conflicting factors in process safety judgements [28] in order of most important, to least important. The interviewer presented the six criteria along with their definitions (provided in Table 2) and allowed participants to review the criteria and ask clarifying questions before ranking them. Participants were encouraged to rank the criteria however they desired, which allowed for ties between criteria. After ranking the six criteria, participants were asked probing questions to determine the rationale behind their rankings, determine if there are criteria they attempted to balance, or identify any context that would change their rankings. Once participants were comfortable with their rankings, we moved to the second section of the interview.

Table 2. Process safety criteria identified in the conceptual framework [26], [28].

Criteria	Definition
Safety	Preventing injuries to people/plant machinery or environmental effects that may occur from chemical leaks that get into the air or waterways.
Production	The bottom line that your company or employer wants you to meet, output from the plant facility. Getting things done.
Leadership	Management of 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.
Spending	Sticking to company budgets and reducing expenses
Time	Availability to spend time with family, participate in hobbies, and invest in your career.

In the second section of the interview, participants were presented with five hypothetical scenarios, which had two responses they could choose from. Participants were asked to approach the hypothetical scenarios from the perspective of a chemical plant manager. Participants read through the hypothetical scenarios and the potential responses before discussing their thought process towards the process safety judgment with the interviewer. Some scenarios had additional context which was provided to participants if they asked for additional context before making their judgment, or after they had made their judgment to see if it would influence their response. Participants were asked probing questions about the rationale behind their judgment if there was anything that may cause them to change their judgment, and what influenced their judgment.

Data Analysis

Interviews with the participants were conducted on Zoom, which was used to record the interview process and to provide a pre-generated transcript. Transcripts from the interviews were reviewed for clarity and accuracy by one researcher. Two researchers then independently reviewed the transcripts to analyze the participants' responses and generate an analytic memo [29]. The analytic memos summarized the interview transcripts and began to identify themes appearing in the participants' responses. These emergent themes were used to connect trends in approaches to process safety judgements across the three participants, which guided the inductive thematic coding process resulting in the codebook (Table 3) [29],

[30]. The two researchers reviewed transcripts using the codebook, making necessary adjustments until the final codebook was completed.

Research Quality

The Qualitative Research Quality (Q3) framework was used to ensure high quality data collection and analysis for this qualitative study, focusing specifically on communicative validation, and process reliability [31], [32]. Communicative validation ensures that the data collected captures the participants' inter subjective reality [31], [32]. Communicative validity was achieved by providing definitions of the criteria being discussed during the interviews, allowing participants to ask clarifying questions, and by asking participants probing questions or confirmatory questions to ensure the researchers understood the reasoning behind their responses. Process reliability ensures that the data collected and recorded is dependable, and is independent from other influences [31], [32]. Process reliability was achieved by having two members of the research team participate in all interviews; one member would conduct the interview while the other member would take notes on participants' behaviors and responses. All interviews were recorded and transcribed before being validated by a member of the research team. An audit trail was kept which recorded all the steps that were taken during the study, and any changes in the study design or data analysis processes.

Limitations

Limitations for this study include a small sample size of industry professionals (n=3), two of which worked at the same company. Additionally, all three participants held a process safety role or equivalent role at their company. While results from this study provide valuable insight, it is important to recognize that our findings are not representative of the broader population of industry professionals due to the small sample size. These trends also may have emerged due to the shared mindset of those holding similar job roles, or due to company policy or culture of the participants working for the same company. Future iterations of this project include recruiting industry professionals working for a variety of companies, within various job roles which still interact with process safety.

Another potential limitation of this study pertains to the method of capturing participants' beliefs through interviews, which reflects their hypothetical responses and espoused beliefs rather than real-life behaviors. While these interviews provide valuable insights into practitioner's beliefs toward their approach to process safety judgements, there is no guarantee it would align with their real-world behavior. Other studies as a part of this work seek to identify the differences in students' espoused beliefs and their behaviors within a digital process safety game [26]. However, we chose to only focus on the beliefs interviews in this study to identify differences in beliefs about how students and industry practitioners would approach process safety judgements.

Results & Discussion

This section will provide results obtained from the interviews to answer the two posed research questions and situate them within the context of relevant skills acquisition literature.

RQ1: What do practitioners believe about how they will approach process safety judgments?

To answer this research question, we identified five overarching themes that were present among the industry participants in the beliefs interview in describing how they believe they will approach process safety judgments. (Table 3).

Table 3. Themes Identified about Industry Professionals' Beliefs about their Approach to Process Safety Judgments

Industry professionals believe they will approach process safety judgments by…		
Code	**Subcode**	**Definition**
Treating safety as a value (n=3)		Recognizing that safety is a value and is not something that can be reprioritized. Safety is paramount.
Acknowledging their job role limitation (n=2)		Acknowledging that they need to work within the bounds of their job role and recognizing when they don't have the competency to do something that another job role is responsible for.
Building context through… (n=3)	Asking for additional details (n=3)	Seeking additional context related to a judgment to help guide responses.
	Supplying hypothetical conditions (n=2)	Supplying novel context which was not provided by the interviewer to help guide responses.
	Connecting their responses to personal experience (n=3)	Supplying context related to a personal experience to help guide responses.
Acknowledging that criteria are weighed against one another, specifically… (n=3)	Safety and production (n=2)	Acknowledging that safety and production are competing for the top priority.
	Safety and spending (n=2)	Acknowledging that safety and spending are competing for the top priority.
Acknowledging relationships as… (n=3)	Motivators (n=3)	Viewing relationships as a goal to work in a more positive way.
	Something to be leveraged (n=2)	Using relationships in a way that is personally beneficial.

All participants described the role of safety in their beliefs about how they make process safety judgments, often stating that safety was not a priority, but rather an unshakable value (code: treating safety as a value). Craft described this by saying

> *'Safety is a value' means it's part of your core belief system, and that it's like embedded ingrained in everything. So no matter what the priority is or what the decision making is, it's basically like what we call like, baked into like any meetings, discussion, thought process, these decisions about what goes on in the plant.*

Although participants recognized the importance of safety, they were also able to identify when other criteria were competing with safety (code: acknowledging that criteria are weighed against one another). The two that were identified specifically were production and spending. Two participants recognized how safety and production can compete. Craft stated

> *Those two* [Safety and Production] *are definitely going to meet somewhere…it's [critical] that we keep our processes safe. But there's a reason why we have those processes in the first place. You're making product for a reason, it's your business model, and you're in business to do that and sell it.*

Similarly, participants recognized that spending and safety were often competing for top priority as well. Participants identified that it usually costs money to have the safest processes, which is not always the most feasible option. Domino stated, *"To do something right and to do something safe, a lot of times you have to spend money and time,"* which was supported by Craft who said *"You could design the most*

inherently safe chemical plant, but it might not be, you know, economical… You might not ever be able to justify operating a plant like that."

Participants also noted the extent of their abilities within their job roles and identified when something fell beyond the reach of their capabilities (code: acknowledging their job role limitation). This was present in two of the participant interviews (Craft and Domino), in which each approached their job roles in different ways. Domino acknowledged how their job role influenced their judgments, stating that they would prioritize safety because "*I'm CHO* [Chemical Hygiene Officer]*, so that's kind of my job."* Craft took a different approach, acknowledging the limits of their job role when ranking the six criteria, stating "*The next one that I put was leadership, and in most of my assignments I haven't really managed somebody else. I've just been responsible for myself."*

Some of the more commonly shared themes identified in the practitioners' transcripts are indicative of a proficient or expert level of skills acquisition. One example is the context the practitioners would create or request when responding to a hypothetical scenario. Individuals at the proficient and expert levels use situational context instead of following a rule-based approach when making judgments [10], [20]. When faced with hypothetical scenarios, participants almost always asked for additional context or provided their own context in response to the scenarios, instead of taking a context-free approach that is indicative of an individual operating in the earlier stages of skills acquisition. This was a major theme that was identified across all three participants (code: building context through asking for additional details/supplying hypothetical conditions). For instance, participants may ask for additional context from the interviewer or build their own context by supplying hypothetical conditions, which we defined as novel context that was not originally provided to them by the interviewers. For example, when asked if they would help an employee complete their overtime forms, Domino stated

> *If this is the first time this person is asking me, I have no problem* [with] *it being A* [helping their employee complete the overtime form]. *If this is the fourth time someone's asking me, I'm going to tell him to do B* [ask a co-worker to help them complete their overtime form].

As mentioned previously, experience is also a large component when advancing through the stages of skills acquisition, since it informs an individuals' perspective when making judgments [10], [20]. Participants often relied on previous experience when making judgments by recalling similar situations, how they behaved in that moment, and the outcome of their decision. Most commonly, participants would rely on their previous experience if they felt they did not have enough context to inform their response. While they may have not experienced the exact scenario before, they would attempt to connect their response to a way they had behaved in a similar scenario which they've experienced. When responding to a scenario about keeping operators on overtime to cover injured operators, Craft said "*We're kind of dealing with or seeing some of that right now, where you know different people may be out for different reasons. And they're covering their positions with overtime."*

Finally, practitioners recognized the role relationships had when approaching process safety judgments, either as a motivator or something to be leveraged. When advancing into later stages of skills acquisition, an individual becomes involved in the outcome of their decisions, and the implications their decision may have on others [10], [20]. The practitioners in this study were able to recognize how their judgments would impact relationships with their co-workers and family, indicating that they have a level of commitment on par with the proficient or expert level of skills acquisition. For example, the relationships criterion was often mentioned by the industrial participants (code: acknowledging relationships), however, there were different ways relationships impacted their process safety judgments. Participants described their relationships with their family, friends, and co-workers as motivators to work more positively. Domino identified the role of their family when making process safety judgments, stating *"It is important for me to get my work done. I also have an obligation to the family. And I want to be home*

with my family, and also my person." Similarly, Craft reflected on the impact their co-workers have on their judgments, saying *"I've been very lucky to have good groups of people that I've worked with in the different assignments that I've had. If you don't enjoy going to work, it really makes getting through a day difficult."*

In a different approach, participants also talked about relationships with their managers and operators as something to be leveraged. This is best represented by Bingo, who said

> *I think getting to know each other on at least a somewhat personal level, kind of understanding people's, backgrounds, and things that influence people's thought processes. It helps when you engage in conversations about some of, like, the kind of the tough issues that you would tackle on a chemical plant and environment. And if you kind of have that perspective, you kind of understand, like, if the people understand you, and you understand them… It can make some kind of tricky decisions a little bit easier to make.*

Participants often mentioned focusing on relationships in the beginning, so they could rely on that person to have their back when making judgments in the future.

Results from the industry practitioner study show that practitioners are using previous experience or are pulling on situational context to inform their judgments. Additionally, practitioners are acknowledging relationships and considering ways in which their judgments may impact those around them. The initial results from this industry professional pilot study support our hypothesis that industry professionals will fall within the proficient or expert levels of the skills acquisition framework.

RQ2: What differences exist, if any, between how industry professionals' and undergraduate engineering students' believe they will approach process safety judgments?

To answer this research question, we refer to the previously mentioned student studies that identified how senior undergraduate engineering students believe they approach process safety judgments [26], [27]. Ritz et al. [26] conducted a small-scale study on three undergraduate engineering students using the same three-phase study design as the one reported in this paper. Stransky et al. [27] then applied these methods to a large scale study which included 14 undergraduate chemical engineering students in a process safety course. Results from these studies are used to inform undergraduate engineering students' level of skills acquisition and are compared to the results we obtained from practitioners to highlight the Theory-to-Practice gap within the context of process safety.

Commitment - Relationships

Ritz et al. [26] analyzed initial interviews for themes regarding student beliefs about approaches to process safety judgments in a small-scale study which included three students. This study found that all three students believed relationships would not have an impact on their process safety judgments. When faced with hypothetical scenarios that could impact their relationships with others, or involve conflict, the students remained unaffected when making their judgments. Students identified that judgments that had the potential to harm a relationship were more difficult to make, but ultimately never made a judgment to benefit a relationship [26].

These results could indicate that students are operating at the novice or advanced beginner stage of skills acquisition, as they are not involved in the outcomes of their judgments, and how they are impacting relationships with those surrounding them. For an individual to take the next step of skills acquisition to the competent stage, they must take responsibility for their actions, and have an emotional involvement in the outcomes of their judgments [10], [20]. For students, developing a sense of commitment to their responses may be difficult due to in-class problems lacking real-world implications [24], which could

affect students' understanding how their judgments impact or are impacted by relationships. Students remained unaffected by relationships when responding to process safety scenarios, and often gave the relationships criteria a low ranking in their beliefs interview [26]. Students acknowledged that the judgments involving relationships were harder to make, and identified how their response may impact another person, but overall did not make a judgment in favor of relationships [26]. In comparison, industry professionals that were identified as being at either the proficient or expert level were influenced by their relationships with their families, co-workers, and managers when making process safety judgments, either seeing relationships as motivators to work toward a more positive outcome or as something that could be leveraged when making future judgments.

It is important that students recognize the role relationships play in process safety. Relationships have appeared as a critical component of previous process safety incidents, such as the Chevron refinery fire. All the engineers who were aware of the leak neglected to shut down operations for fear of backlash from their other co-workers. Ultimately, wanting to maintain a reputation resulted in a fireball [33]. This behavior is emphasized by Baybutt [14] who stated that important considerations in decision-making may be overlooked since people can be persuaded by emotion or reputation.

Components - Situational Context & Experience

Students and industry professionals may also be operating at opposite levels of the skills acquisition framework due to the different amounts of experience they have. Preliminary results from a later large-scale student study [27] showed that students would often draw from their lived experiences to justify their responses. Students who previously had an internship would rely on the context gained from their role to guide their responses, while students without internships would rely on experience gained from the classroom, or retail employment. Overall, students lacked the experience which would provide situational context that would inform their perspective when making a judgment [27]. The few students that had held internship positions would recall previous situations to inform their responses. Echo, a student who had an internship, supported their prioritization of safety by saying "*I'd say this is heavily influenced by my prior internship that I've done, where the company was very keen on safety, and it was the number one thing."* Those without internships would rely on experience gained from the classroom, or retail employment. Lemon reflected on a lesson from their chemistry class when ranking the safety criteria, stating

> *The first little bit of the class he was focusing on... a leak in it was another country. But it was a really bad leak, and it basically like killed thousands of people, and they just try to cover it up and say that, like someone did it intentionally, but in reality, it was just that, like the plant, wasn't safe to be at, and like they weren't fixing pipes and stuff. And I think the reason why I think safety is so…extremely important.*

While students are relying on their previous experience to respond to judgments, they are lacking the situational context in relation to process safety. Additionally, students seem to still be following an analytic, rule-based approach when recalling experience. Echo seemed to prioritize safety because that's what their company prioritized. Similarly, Lemon was taught in class the failures that can occur when safety is not prioritized, which appeared to result in them prioritizing safety. Industry professionals have more experience within the process safety field and understand the situational context that may influence their judgments. They are able to call on previous experience to construct context that would guide their responses. As individuals gain experience and are exposed to different contexts, they begin to rely on previous situational contexts when making judgments [10]. We see industry professionals do this, as they use their prior experience to construct context to make a judgment where little context is available to them.

Conclusions

This industry professional pilot study investigated the Theory-to-Practice gap within the process safety field. We interviewed three industry professionals to understand how they believe they would approach process safety judgments and compared these responses to those of senior chemical engineering students who had previously completed the same study. Findings from the practitioner study revealed that industry professionals were influenced by their relationships with their families, co-workers, and managers when making process safety judgments. Industry professionals would prioritize relationships when making judgments to work toward a more positive outcome or would leverage relationships as something that could benefit future judgments. This contrasted with students, who were not affected by relationships when making judgments. While students acknowledged the presence of relationships, or mentioned how the relationship made the judgment more difficult they were ultimately not influenced by the relationship when making their judgments.

Additionally, we recognized the use of previous experience when describing beliefs about how individuals would approach making process safety judgments. Both industry professionals and students relied on their previous experiences when describing their beliefs about their approach to process safety judgments. However, due to the students' lack of process safety experience, they would instead recall previous experiences from the classroom, retail jobs, or internships. Students would use their previous experience to support the judgments they had made based on the context that was given to them. Additionally, as students had little to no experience in the process safety industry, they attempted to draw parallels from their lived experiences to the process safety scenario they were faced with. Industry professionals would also use previous experience to guide their responses, however, they would use previous experience to construct context where it was lacking to make a judgment rather to support a judgment they had already made. Industry professionals also have more experience within the process safety field and understand the situational context that may influence their judgments.

Results from this industry professional pilot study and previous student studies show that industry professionals are operating at the proficient and expert levels of skills acquisition, while students are in the novice to advanced beginner levels of skills acquisition. According to the Dreyfus [10] model of skills acquisition, four components impact how an individual progresses through the levels of skills acquisition: components, perspective, decision, and commitment. Literature shows the effect experience has on these components, especially perspective and intuition. As an individual is faced with more judgments and scenarios, their repertoire of previous experience grows, changing their perspective to experienced rather than having none [10]. Additionally, intuition is something that comes with experience, causing individuals to make less analytic, rule-based judgments and more quick decisions based on their prior experiences [10], [21]-[23], [25]. While we cannot teach students the experience of an industry professional within a classroom, we can attempt to advance their skills acquisition by exposing them to the situational context that may influence their judgments and attempt to make them more involved in the outcomes of their decisions. Implementing frameworks such as the cognitive apprenticeship framework which focuses on novices learning the problem-solving process of experts from experienced professionals may be useful in addressing this gap [19]. Our future research in this area hopes to explore the impact of such frameworks on students' skill acquisition in a process safety course.

References

[1] Zhiqiang Gao and R. R. Rhinehart, "Theory vs. practice: The challenges from industry," in *Proceedings of the 2004 American Control Conference*, Boston, MA, USA: IEEE, 2004, pp. 1341–1349. doi: 10.23919/ACC.2004.1386761.

[2] R. R. Rhinehart, "Understanding the Rationale Behind the Academic-Practice Gap," Control. Accessed: Aug. 24, 2023. [Online]. Available: https://www.controlglobal.com/manage/asset-management/article/11303683/understanding-the-rationale-behind-the-academic-practice-gap

[3] S. R. Brunhaver, R. F. Korte, S. R. Barley, and S. D. Sheppard, "Bridging the Gaps between Engineering Education and Practice," in *U.S. Engineering in a Global Economy*, Chicago ; London: The University of Chicago Press, 2018, pp. 129–163.

[4] R. R. Rhinehart, "Is a college education enough to get young engineers ready for the workforce?," Control. Accessed: Jul. 25, 2023. [Online]. Available: https://www.controlglobal.com/home/article/11326520/is-a-college-education-enough-to-get-young-engineers-ready-for-the-workforce

[5] B. Díaz, C. Delgado, K. Han, and C. Lynch, "Use of Communities of Practice to Analyze and Improve Graduate Engineering Education.," presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Jan. 05, 2024. [Online]. Available: https://peer.asee.org/use-of-communities-of-practice-to-analyze-and-improve-graduate-engineering-education

[6] C. F. Lynch, K. Han, C. Delgado, and B. A. Díaz, "Improving Graduate Engineering Education through Communities of Practice Approach: Analysis of Implementation in Computer Science, Robotics, and Construction Engineering Courses," presented at the 2023 ASEE Annual Conference & Exposition, Jun. 2023. Accessed: Jan. 05, 2024. [Online]. Available: https://peer.asee.org/improving-graduate-engineering-education-through-communities-of-practice-approach-analysis-of-implementation-in-computer-science-robotics-and-construction-engineering-courses

[7] C. Gupta and V. Gupta, "*C* 4 Skills in the Engineering Graduate: A Study to Align Software Engineering Education With Market-Driven Software Industry Needs," *IEEE Trans. Educ.*, pp. 1–13, 2023, doi: 10.1109/TE.2023.3301625.

[8] D. M. C. Nascimento, C. Von Flach Garcia Chavez, and R. A. Bittencourt, "Does FLOSS in Software Engineering Education Narrow the Theory-Practice Gap? A Study Grounded on Students' Perception," in *Open Source Systems*, vol. 556, F. Bordeleau, A. Sillitti, P. Meirelles, and V. Lenarduzzi, Eds., in IFIP Advances in Information and Communication Technology, vol. 556. , Cham: Springer International Publishing, 2019, pp. 153–164. doi: 10.1007/978-3-030-20883-7_14.

[9] "U.S. Chemical Safety and Hazard Investigation Board | CSB." Accessed: Sep. 13, 2023. [Online]. Available: https://www.csb.gov/

[10] S. E. Dreyfus, "The Five-Stage Model of Adult Skill Acquisition," *Bulletin of Science, Technology & Society*, vol. 24, no. 3, pp. 177–181, Jun. 2004, doi: 10.1177/0270467604264992.

[11] "BP America (Texas City) Refinery Explosion | CSB." Accessed: Dec. 11, 2023. [Online]. Available: https://www.csb.gov/bp-america-texas-city-refinery-explosion/

[12] "Bayer CropScience Pesticide Waste Tank Explosion | CSB." Accessed: Dec. 11, 2023. [Online]. Available: https://www.csb.gov/bayer-cropscience-pesticide-waste-tank-explosion/

[13] "Formosa Plastics Vinyl Chloride Explosion | CSB." Accessed: Dec. 11, 2023. [Online]. Available: https://www.csb.gov/formosa-plastics-vinyl-chloride-explosion/

[14] P. Baybutt, "A framework for critical thinking in process safety management," *Proc. Safety Prog.*, vol. 35, no. 4, pp. 337–340, Dec. 2016, doi: 10.1002/prs.11858.

[15] L. Duesund and E. Jespersen, "Skill Acquisition in Ski Instruction and the Skill Model's Application to Treating Anorexia Nervosa," *Bulletin of Science, Technology & Society*, vol. 24, no. 3, pp. 225–233, Jun. 2004, doi: 10.1177/0270467604265011.

[16] L. Maddy and L. Rosenbaum, "Determining leadership levels with the Dreyfus model," *JWL*, vol. 30, no. 8, pp. 626–639, Nov. 2018, doi: 10.1108/JWL-11-2017-0100.

[17] I. Mohedas, S. R. Daly, and K. H. Sienko, "Use of Skill Acquisition Theory to Understand Novice to Expert Development in Design Ethnography," *International Journal of Engineering Education*, vol. 32, no. 3(B), pp. 1364–1371, 2016.
[18] S. E. Dreyfus and H. L. Dreyfus, "A Five-Stage Model of the Mental Activities Involved in Directed Skill Acquisition:," Defense Technical Information Center, Fort Belvoir, VA, Feb. 1980. doi: 10.21236/ADA084551.
[19] A. Collins, J. S. Brown, and S. E. Newman, "Cognitive Apprenticeship: Teaching the Crafts of Reading, Writing, and Mathematics," in *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser*, L. Erlbaum Associates, 1989, pp. 453–494.
[20] P. Benner, "Using the Dreyfus Model of Skill Acquisition to Describe and Interpret Skill Acquisition and Clinical Judgment in Nursing Practice and Education," *Bulletin of Science, Technology & Society*, vol. 24, no. 3, pp. 188–199, Jun. 2004, doi: 10.1177/0270467604265061.
[21] E. Miskioglu and K. Martin, "Is it Rocket Science or Brain Science? Developing an Instrument to Measure 'Engineering Intuition,'" in *2019 ASEE Annual Conference & Exposition Proceedings*, Tampa, Florida: ASEE Conferences, Jun. 2019, p. 33027. doi: 10.18260/1-2--33027.
[22] E. Miskioglu and K. Martin, "Is the Answer Reasonable or Ridiculous? Common Factors among Students Who Display High Engineering Intuition on Technology-aided Solutions," in *2017 ASEE Annual Conference & Exposition Proceedings*, Columbus, Ohio: ASEE Conferences, Jun. 2017, p. 28592. doi: 10.18260/1-2--28592.
[23] E. E. Miskioğlu *et al.*, "Situating intuition in engineering practice," *J of Engineering Edu*, vol. 112, no. 2, pp. 418–444, Apr. 2023, doi: 10.1002/jee.20521.
[24] J. Stransky, "EXPLORING SENIOR CHEMICAL ENGINEERING STUDENTS' APPROACH TO PROCESS SAFETY DECISION MAKING," *Theses and Dissertations*, May 2023, [Online]. Available: https://rdw.rowan.edu/etd/3122
[25] C. Aaron, E. Miskioglu, K. M. Martin, B. Shannon, and A. Carberry, "Nurses, Managers, and Engineers – Oh My! Disciplinary Perceptions of Intuition and Its Role in Expertise Development," in *2020 IEEE Frontiers in Education Conference (FIE)*, Uppsala, Sweden: IEEE, Oct. 2020, pp. 1–6. doi: 10.1109/FIE44824.2020.9274026.
[26] C. Ritz, J. Stransky, C. A. Bodnar, E. Dringenberg, and E. Miskioglu, "Criteria Conundrum: Engineering Students' Beliefs about the Role of Competing Criteria in Process Safety Judgements," presented at the 2023 ASEE Annual Conference & Exposition, Jun. 2023. Accessed: Dec. 11, 2023. [Online]. Available: https://peer.asee.org/criteria-conundrum-engineering-students-beliefs-about-the-role-of-competing-criteria-in-process-safety-judgements
[27] J. Stransky, B. L. Butler, C. Ritz, E. Dringenberg, E. Miskioglu, and C. A. Bodnar, "Board 419: Students use their Lived Experiences to Justify their Beliefs about How they Will Approach Process Safety Judgment," presented at the 2023 ASEE Annual Conference & Exposition, Jun. 2023. Accessed: Dec. 11, 2023. [Online]. Available: https://peer.asee.org/board-419-students-use-their-lived-experiences-to-justify-their-beliefs-about-how-they-will-approach-process-safety-judgment
[28] J. Stransky *et al.*, "Impact of Immersive Training on Senior Chemical Engineering Students' Prioritization of Process Safety Decision Criteria," presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: Jan. 05, 2024. [Online]. Available: https://peer.asee.org/impact-of-immersive-training-on-senior-chemical-engineering-students-prioritization-of-process-safety-decision-criteria
[29] J. Saldaña, *The coding manual for qualitative researchers*, 3. edition. Los Angeles, Calif. London New Delhi Singapore Washington DC: SAGE, 2016.
[30] J. Ritchie, Ed., *Qualitative research practice: a guide for social science students and researchers*, 2. ed. Los Angeles, Calif.: Sage, 2014.
[31] J. Walther, N. W. Sochacka, and N. N. Kellam, "Quality in Interpretive Engineering Education Research: Reflections on an Example Study," *J of Engineering Edu*, vol. 102, no. 4, pp. 626–659, Oct. 2013, doi: 10.1002/jee.20029.

[32] J. Walther *et al.*, “Qualitative Research Quality: A Collaborative Inquiry Across Multiple Methodological Perspectives,” *J of Engineering Edu*, vol. 106, no. 3, pp. 398–430, Jul. 2017, doi: 10.1002/jee.20170.
[33] “Chevron Richmond Refinery Fire | CSB.” Accessed: Jan. 05, 2024. [Online]. Available: https://www.csb.gov/chevron-richmond-refinery-fire/

Appendix A

Note: This protocol has also been reported in Ritz et al. [26]

Beliefs Interview Protocol Script

Date: _____

Time: _____

Interviewer: _____

Pseudonym: _____

All interviews aim to identify engineering professionals' concrete decision-making behavior and their beliefs about the roles of different approaches to decision making. This will include the consistent use of follow-up questions such as, “why?,” “why do you believe that?,” “tell me more about that,” and “what do you mean when you say that?” to help further elucidate responses to the prompts.

Interview Protocol

1. Feeler questions to build some rapport:
    a. Starting off, we will use a fake name, or pseudonym, to identify your data so that your actual identity remains confidential. What name would you like us to use for the data you provide in this interview?
    b. Okay, NAME, we are going to start recording our conversation now? This is just to help us take better notes and keep track of what we’ve talked about.
    c. What is your current job title?
    d. What is your role in process safety?
    e. How did you come to where you are as an engineering practitioner now?
    f. Have you thought much about where you would like to go next with your career?

2. **Background for the context**: The purpose of this conversation is to help us as researchers understand how 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…

3. 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.

Okay, thanks. Can I clarify any of these terms for you--anything confusing?

Great, thanks. 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?

4. 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*:]
    a. _____ looks to be the most important criterion to you. Why is that?
    b. These criteria seem to be tied in importance. Can you talk about why you believe they are equally important?
    c. It appears that _____ is the least important criterion to you. Why is that?
    d. So what I am hearing is that _____. Is that correct?
    e. So you think ____ is more important than _____ and _____? Is that right? Why do you think that?
    f. If trying to balance any criteria instead of ranking in a hierarchy, please explain why you want to balance certain things.
    g. Are there any situations or contexts where you might change your rankings? Why?
    h. [Let them lead trying to pick hierarchies, but if they are looking to balance some criteria, invite them to balance them].
    i. Let me check my notes, and see if there is anything else I want to follow up on…

5. Okay, 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 [*show via screen share*].

    a. [*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?

b. [*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?

c. [*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.

d. [*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.

e. [*Production and Safety*:] You had to stop production in the plant due to a nasty hurricane. Due to previous incidents, two of your engineers are on injury leave. Your supervisor, Wanda, approaches you and demands, “Alright, what is happening down there? Every day the unit isn’t running is affecting profit.” Your options are to respond with “I'm trying my best, but two operators are injured. We're pushing through the night. [*production*] or “My top priority is getting my two injured employees medical attention. Profit can wait.” [*safety*] Which would you choose and why?

- [*Add context as they need it here*:] The hurricane has resulted in a full day of lost operations.
- [*Add context as they need it here*:] Both operators were hospitalized from their injuries.

6. 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*:]
    a. _____ looks to be the most important criterion to you. Why is that?
    b. These criteria seem to be tied in importance. Can you talk about why you believe they are equally important?
    c. It appears that _____ is the least important criterion to you. Why is that?
    d. So what I am hearing is that _____. Is that correct?
    e. So you think ____ is more important than _____ and _____? Is that right?
    f. If trying to balance criteria instead of ranking in a hierarchy, please explain why you want to balance certain things.
    g. Are there any situations or contexts where you might change your rankings? Why?
    h. [Let them lead trying to pick hierarchies, but if they are looking to balance some criteria, invite them to balance them].
    i. Let me check my notes, and see if there is anything else I want to follow up on…

7. "Is there anything else you want to add or you think we missed or didn't get to cover"

8. 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. We ask that you complete Contents Under Pressure by February 16th, 2024 so that we can have some time to pull your game data. We will send you a quick-start guide on how to get your account set up with Contents Under Pressure at the conclusion of this meeting. After playing the game, we will schedule one more interview with you in February or March. Do you have any questions at this time?