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Process Safety Judgments: Comparing Students' and Practitioners' Perspectives

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Abstract

Process safety judgments are routinely a part of a chemical engineering career, but chemical engineering students might not necessarily anticipate the variety of situational elements that impact these judgments. Factors such as relationships, safety cultures, and pressures from budgets or production have all influenced previous judgments resulting in process safety failures. Although process safety education focuses on equipping students with process safety concepts, techniques, and approaches, the current pedagogical methods struggle to simulate real-world judgments. As a result, there may be a Theory-to-Practice gap that exists between students and practitioners.

The Theory-to-Practice gap accounts for the time it takes for an engineering student to become an effective contributor in their workplace. This gap can be due to a variety of factors such as complex topics being taught through simple, textbook problems, difficult or lack of opportunities to combine knowledge from different courses to solve realistic problems, or the lack of time students have to master these concepts. A model that can be used to help identify whether the theory to practice gap exists by delineating skills across different stages of expertise is the Dreyfus Five-Stage Model of Adult Skills Acquisition. This study applies the Dreyfus Five-Stage Model of Adult Skills Acquisition to student and practitioner responses to process safety judgments to identify if there are any differences between these two populations. Specifically, as part of the work presented here we examine:

RQ1) What differences exist between chemical engineering students & experienced practitioners' perspectives when making process safety judgments? and *RQ2) What differences exist in perspectives based on participants' skills acquisition level?*

To answer these research questions, two groups of participants were interviewed using the same data collection protocol; 17 practicing engineers with varying years of experience who had worked in process safety, and 11 chemical engineering students (1 junior, 10 seniors) enrolled in a senior design course. Data was collected through interviews where participants responded to five process safety scenarios and provided rationale for their responses. Participants' responses were coded holistically for their perspectives using a codebook deductively developed from the Dreyfus Skills Acquisition model. This study found that students were often concerned with their tone of response or following procedures when making a judgment or would prioritize/deprioritize situational elements when they did not know how to proceed. In contrast, practitioners would rely on previous experience when prioritizing criteria, and would describe next steps to avoid miscommunication, prevent further injuries or incidents, and/or to optimize procedures.

Introduction

Process safety incidents are often influenced by a variety of situational elements, such as production [1], [2], [3], relationships [4], [5], spending [6], [7], and time [8]. As such, it's important that process safety education prepares chemical engineering students for the complexity of these judgments. Currently, process safety courses equips students with technical and contextual knowledge that increase competencies associated with safe and efficient work [9], [10], and has the potential to prevent accidents in the future through lessons learned, constant safety vigilance, and the development of new knowledge [11]. However, to successfully teach students process safety, it's important to use pedagogical methods that reflect real-world judgments, and all the situational elements that are considered in those moments [10], [12]. Currently, this is completed through the use of process safety case studies.

Case studies have been widely used in process safety education [13]-[17], and are one of the most common approaches for teaching process safety [13]. Case studies prepare students for real-world process safety judgments by allowing students to apply strategies and knowledge from their courses to find concrete, real-world solutions [11], [18], [19]. Additionally, case studies can help prepare students for their future employment as they help students develop practical skills, leadership, management, and technical skills when responding to complex system failures [19]-[21]. However, there are limitations within case studies particularly those that do not expose students to the complexity of the judgments that were made within these safety incidents. The limitation of time alone often does not let students expand into the underlying safety issues or situational elements surrounding the judgments made, leading to an over-simplification of nuances that impact process safety incidents, or simple cause-and-effect analyses rather than a holistic understanding of the event [13], [21]. Additionally, students tend to succumb to hindsight bias as they review case studies, since they are reviewing all of the information at once, leading them to believe they would not make the same mistakes as the individuals involved in the process safety incident [21]-[23]. Finally, process safety case studies can over-emphasize safety and downplay other criteria, leading students to ignore situational elements like production, time, and relationships in favor of safety [24].

These methods of teaching process safety may be contributing to what is commonly known as the Theory-to-Practice gap. The Theory-to-Practice gap defines the amount of time it takes for a student to adapt to their new workplace and become an effective contributor, and can be brought on by a variety of factors. Often, students learn complex and fundamental engineering concepts through simple and sanitized textbook problems that do not reflect the complications involved with real-world problem solving [25], [26]. Additionally, students have difficulty combining knowledge from different domains to solve realistic problems [25], so they struggle to make connections between their technical knowledge and practice [27], [28]. In process safety courses, chemical engineering students are provided with case studies that prioritize safety, and place other situational elements like production, time, or relationships in a negative role [1], [7], [29]. Realistically, engineers are expected to balance these elements in a way that keeps everyone safe, but still ensures that productivity is in the green, and relationships with employees and leaders are maintained [24].

A possible method that could be used to measure if a Theory-to-Practice gap is manifesting related to process safety judgments is the Dreyfus Five-Stage model of Adult Skills Acquisition, which explains an individual's progression from novice to expert as they develop their components, perspective, decisions, and commitment [30]. This study applies the Dreyfus Skills Acquisition model to student and practitioner responses to process safety scenarios to determine what differences exist, with a specific emphasis on perspectives.

Background

Process Safety Management, or PSM, is required for any company operating with highly hazardous materials or processes [31]. However, process safety judgments are very complex due to the variety of situational elements that may influence them, such as productivity, reputation, and time. While students believe they will make the right judgments and prioritize safety in the workplace, research has shown that they unconsciously prioritize other situational elements such as personal relationships and productivity when placed in real-world contexts [32]-[35]. As such, it is important that engineering students entering the workforce are prepared for the complexity of judgments they may face.

Process Safety Judgments

Poor process safety judgments have been found to be influenced by situational elements such as productivity, reputation, and poor leadership. Often, safety is pit against bottom line or production in industry, which has led to previous process safety incidents. For example, the Chevron Refinery Fire that occurred in 2012 and resulted in the release of a vapor cloud that eventually led to a fireball was partially due to the prioritization of production, time, and spending over safety. Similarly, a chemical leak at Freedom Industries was the result of pitting in the tank, a lack of maintenance inspections, and a missing secondary containment system. The management team was aware of these deficiencies, but chose to prioritize spending and production over safety, leaving over 300,000 people without access to water, and putting close to 400 people in the hospital [6]. Literature has also cited that pressures from cost and time often lead to poor process safety judgments [8].

Other situational elements such as relationships and reputation have also been shown to influence process safety judgments. Baybutt [36] identifies that people may be persuaded by emotions such as fear or pleasure when making judgments, or also consider the position or reputation of others instead of critical thinking and logic [5]. Previous recorded process safety incidents seem to support this claim. Another factor in the previously mentioned Chevron Refinery Fire was co-workers making judgments to avoid getting "flack," or negative feedback, from their co-workers [1]. A hydrogen sulfide release at Aghorn Operations Inc. led to the death of one worker and their spouse. Their spouse should not have had access to the waterflood station where the leak occurred, but judgments made due to their relationship led to an unnecessary death [4].

Poor leadership and safety culture have also contributed to process safety judgements that resulted in incidents. A runaway reaction at Bayer CropScience left two employees fatally injured when a waste task exploded [37]. Upon investigation, the Chemical Safety Board (CSB) found that employees were not trained on proper start-up and shut-down procedures, were often encouraged to deviate from written procedures, and were fatigued from being overworked [37]. Similarly, a liquid nitrogen release at Foundation Food Group led to six fatalities, and left many others injured [3]. The CSB found that employees had not been trained on the hazards of liquid nitrogen, or proper emergency procedures if a leak occurred due to the nitrogen freezer, which had been recently installed to improve production capacity [3].

The literature and incidents discussed here emphasize the situational elements that are still impacting current process safety judgments and highlights the need to adequately prepare current engineering students for the complexity of judgments they will face in industry. Currently, the best place for this training to occur is within process safety education.

Process Safety Education

Current process safety education focuses on the learning of operating and safety principles through systematic approaches with the goal of avoiding major accidents in the process safety industry [10].

Process safety education equips students with the technical and contextual knowledge that prepares them to face some of the additional considerations surrounding process safety judgments [9], and increases competencies associated with safe and efficient work [10]. Process safety education also encourages life-long learning and continual professional advancement [10], which is a skill required of engineers [25]. Equipped with these knowledge and skills, students will be better prepared to make process safety judgments. Research has shown that process safety education has played an important role in the improvement of process safety in industry, since teaching process safety principles in higher education has led to a decrease in the likelihood of future incidents through safer workplaces, improved efficiency and, and reduced risk [10], [13]. Saleh & Pendley hypothesize in their research that process safety education can also lead to accident prevention through lessons learned, constant safety vigilance, and the development of new knowledge [11].

To successfully teach process safety, it's necessary to use pedagogical methods that expose students to real-world judgments. Real-world problems prepare students for making process safety judgments because they develop process safety competency and awareness [10], [12], and integrate the experiences of professional engineers to teach expert-level problem solving [10], [13]. Real-world problems also have the potential to expose students to the situational elements that influence process safety judgments, as they are often asked to determine the physical causes as well as leadership failures that led to the incident [21], [38], and help prepare them to find solutions in areas of uncertainty [18], [21]. Currently, the most widely used pedagogical method used in process safety education is case studies [13]-[17].

Case studies, or case-based learning, is one of the most common approaches to teaching process safety education [13]. Case studies offer real-world problem solving that allows students to apply process safety principles to real-world problems, and find concrete solutions [11], [14], [18], [19]. Case studies require students to rework open-ended problems to reinforce technical abilities that are placed in the context of real-world engineering [21], and are a useful method in guiding students to understand the relationships between theoretical constructs, practical applications, and contextual concepts [17], [21], [39]. Furthermore, case studies can develop students professional skills relevant to their future employment such as leadership, management, and technical skills in the context of complex system failures [19], [21]. And while case studies have the potential to expose students to the human factors and reflect on contextual factors [11], [17], [21], they contain limitations that do not provide students with the full complexities of the judgments that were made that led to the process safety incident.

Finding the necessary time and resources to allow students to properly explore and discuss case studies can be difficult, leading to an over-simplification of the problem, nuanced details being ignored, or discussions following a simple cause-and-effect explanation [13], [21]. Case studies often provide all the information up front rather than being scaffolded similar to how the original incident unfolded, which could leave them feeling one-dimensional, or shallow. When students are given all the information to analyze at once, it diminishes the complexities of the incident causation, and can lead to them taking the perspective of an investigator, rather than being immersed in the incident [21]. When students are more focused on *how* someone failed to see a warning sign rather than *why* they made the judgment considering all the contextual elements, it can lead to a cognitive bias known as the hindsight bias [22], [23]. Hindsight bias occurs when an individual believes they would not have made the same mistake as someone else after they've been given the information that was not originally available at the time the mistake was made [21], [22]. Hindsight bias can make case studies difficult to review because students are more focused on the warning signs that, in hindsight, are obvious, which can hinder students' understanding of the full context surrounding the original judgments, determining the judgments that led to the incident, and identifying key learning from the incident [15], [22], [23]. Finally, case studies place a large emphasis on prioritizing safety, which could be leading to an anchoring effect [40], where students place their focus on safety, and downplay other elements like production, time, and relationships. In academia, students tend to prioritize safety over everything else [41], even isolating it from other criteria, and believing there would never exist a situation where they would deprioritize safety for another criteria [24]. However, these do not reflect how engineers are expected to make judgments, which involves balancing these criteria to maintain the bottom line while ensuring everyone's safety [24]. The lack of complexity within the process safety classroom may be leaving students underprepared for the judgments they will have to make in industry, ultimately contributing to a Theory-to-Practice gap related to process safety judgments.

Theory-to-Practice Gap

The Theory-to-Practice gap represents the time it takes for a newly graduated student to become an effective contributor in their workplace [25], and is attributed to a variety of reasons. Higher education prefers the use of well-structured problems with minimal context to teach complex concepts, which does not prepare students for the ill-structured problems they will face in the real-world [25], [42], [43]. This hinders students from applying their technical knowledge to real-world problems, so they struggle to see connections between academia and industry [27], [28], [42], [44]. Furthermore, four years is not enough time for students to learn everything they will need to know for their careers, meaning that students should be taught how to become their own problem solvers [12], [25].

The Theory-to-Practice gap can cause problems for multiple stakeholders, from the schools that students come from, to the companies they go to. While it may take everyone a bit of time to adjust to a new role, students moving out of academia can face up to two years becoming "industrialized" [25], during which, companies are spending time and money for trainings and coaching to get newly hired students up to speed [45]. This may lead companies to hire individuals with more experience, making students question the value of their education. Some literature shows that students already notice a disconnect between what they learned in college and what is required in industry [44], which creates a problem for higher education, as students may choose to move away from academia in favor of work experience [46].

To properly address the Theory-to-Practice gap, it is beneficial to gather insight from individuals with expertise in the field. Specifically in process safety, a disconnect between process safety in industry and process safety education has already been identified [47]. Some suggest that successful changes in process safety education cannot be made without input from industry, and that academia is not well-suited to teach the complex interactions that safety depends on [12], [38]. This study seeks to identify the differences in students' and practitioners' process safety judgments, using the Dreyfus Five-Stage Model of Adult Skills Acquisition as the guiding framework.

Dreyfus Five-Stage Model of Adult Skills Acquisition

Making well informed process safety judgments while balancing multiple criteria is a skill engineers are required to develop, and it can be measured using the Dreyfus Skills Acquisition model. This model measures how individuals progress in expertise in a specific field through five stages: Novice, Advanced Beginner, Competent, Proficient, and Expert [30]. Individuals skills acquisition level is based on their development in four areas: Components, Perspectives, Decisions, and Commitment. Components refer to the elements that an individual is able to recognize, and can be context free or situational [30]. In the context of process safety, situational elements could include production, time, and compliance with regulations. Perspectives describe how an individual handles situational elements when making a judgment. Decisions describes how the judgments is made – is it thought out and analytical, or intuitive [30]? Finally, Commitment describes the degree to which the learner is immersed in the situation and progresses from detached, to involved in outcome, to involved in understanding, and then involved in deciding [30]. A table describing the five stages is provided in Table 1.

Table 1: The five stages of skills acquisition [30]

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

The overarching study associated with this work focuses on students' and practitioners' approaches to making process safety judgments, though a full analysis of differences between students' and practitioners' components, perspectives, and commitment is available elsewhere [48]. The specific focus of this paper is on what differences exist between students' and practitioners' perspectives. Perspectives shift as individuals continue to be exposed to different types of situational elements, and progress from a None perspective, to a Chosen perspective, then conclude at an Experienced perspective [30]. In earlier stages of the Skills Acquisition model, Novices and Advanced Beginners approach judgments context-free, or with minor situational context. At this stage, they are still relying on the rules and techniques used to solve well-structured problems, taking on a None perspective [30]. Eventually, the individual realizes that these procedures will not work on every problem and begins to notice the situational contexts surrounding their judgments. They become overwhelmed, and still do not have a clear sense as to what is important in any particular situation [30]. To cope with this overload, individuals will choose a perspective that determines elements they believe are important, and which can be ignored, resulting in the Chosen perspective [30]. Individuals learn from these Chosen perspectives which elements should be prioritized and which should be deprioritized in a variety of situations based on the outcome of their prior choices [30]. Eventually, this collection of situational discriminations becomes large enough that they no longer feel the need to choose a perspective, they just know what the solution to the process safety decision should be, resulting in the Experienced perspective [30].

In this study, we aimed to answer the following two research questions:

RQ1: What differences exist between chemical engineering students' & experienced practitioners' perspectives when making process safety judgments? and

RQ2: What differences exist in perspectives based on participants' skills acquisition level?

Methods

This section will summarize the data collection methods used for this study, and the interview protocol designed to collect data. Additionally, this section describes the data analysis methods used to process and validate the responses, code the data, and analyze the responses. Proper IRB approval was obtained prior to conducting this research. All participants were required to sign a consent form that informed them of the risks and benefits of this work. Participants were also offered a $50 gift card upon completion of the study.

Participants

Practitioners for this study were recruited in two cohorts. First, practitioners were recruited for a pilot study in the Summer of 2023 through personal networks of the research team. Criteria at this time included engineers who worked in a process safety specific role (PSM specialists, members of CCPS, etc.). When moving into the full-scale study, this criterion was relaxed to include a more diverse group of engineers who were only required to have had some involvement in process safety at some point in their careers (e.g. working to meet compliance, involved in audits, etc.) Data collection protocols did not change between these two studies, which allowed all practitioner responses to be combined into a single sample for this study. Practitioners were recruited for the full-scale study in the Fall of 2023 through internal connections, posting to LinkedIn, and at process safety division sessions at a chemical engineering conference. Three practitioners completed the pilot study, and 13 practitioners completed the full-scale study for a total of 16 practitioner responses. It was later discovered that one of the practitioners in the full-scale study was actually a student working in their co-op, and as such was analyzed as a student, resulting in a total of 15 practitioner responses.

Student data was utilized from a previous study that took place in Fall 2022 [49]. In this study, 11 chemical engineering students enrolled at a Southern Atlantic University took part in a three-phase study, whose methods have been described elsewhere [49], [50]. This study analyzed students' responses to the first phase of the study, which used the same data collection protocol as the practitioners, thereby allowing for the data to be analyzed as a single sample, and comparisons to be drawn between the students and practitioners. Although participant responses were collected in 2022-2023, this data was not analyzed for this study until 2025. This data has been analyzed and disseminated in other publications [24], [49]-[51], however, this was the first time the data was analyzed using the Dreyfus Skills Acquisition model, which the protocol had not been intentionally designed for. While it was possible for the responses to be analyzed using this model, it resulted in a delay in this study being completed.

Interviews

As previously mentioned, this study used the data collection protocol from the first phase of a three-phase study [49], [50]. In this protocol, participants took part in a one-hour online interview that was recorded for future analysis. In the first half of this interview, participants were asked to rank six criteria that have been found to impact process safety judgments [35], [52]. In the second half of the interview, participants were asked to respond to five process safety scenarios. Since this study is interested in the differences that may exist between engineering students' and practitioners' engineering judgments, only responses to the process safety scenarios were analyzed.

When completing this portion of the interview, participants were given a process safety scenario, and two options to choose from. They were asked to answer from the perspective of an engineering manager and encouraged to choose the response that would reflect what they believed they would do in that situation. Participants were also encouraged to verbalize why they had made their judgment and were occasionally prompted by the interviewers with probing questions to obtain a deeper understanding of their response (e.g. If x changed, would your response change?). An example of one of these scenarios is provided below [35], [51].

> *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." or*
>
> *"I'm giving her as much time as she needs. We can't afford to lose her."*
>
> *Which would you choose and why?*

Only participant responses immediately following the scenario were analyzed to avoid any modifications to responses that may have been caused by interviewer prompting. In the context of this study, prompting did not include the interview repeating what the practitioner said for clarification, or the practitioner asking the interviewer to clarify the scenario or responses. Prompting did include anytime the participant requested more context, the interviewer providing context that was not given in the scenario, and the interviewer asking probing questions.

Data Processing

All interviews were conducted and recorded on zoom. Transcripts from each interview were verified by members of the research team prior to data analysis, and all participants were assigned a pseudonym to de-identify their data. Student and practitioner responses to the process safety scenarios were analyzed as one sample. To further anonymize data and avoid bias, participants were assigned a random numerical identifier, and responses were shuffled in an excel sheet prior to analysis. After verifying transcripts and removing responses that had been influenced by interviewer prompting, there were 128 passages that were analyzed.

Coding

A codebook was deductively developed based on the Dreyfus Skills Acquisition model to determine which perspective participants were showing when responding to the process safety scenarios. The Dreyfus Skills Acquisition model defined what may appear in a None, Chosen, and Experienced perspective, which was then translated into a process safety context. For example, those with a Chosen perspective feel overwhelmed by the amount of situational elements they have to balance when making a judgment, leading them to prioritize some, or deem others not as important [30]. In the context of process safety, this may look like prioritizing safety over production, or a relationship over time, reflecting the trade-offs that engineers often face in industry [24]. The perspectives codebook is provided below in Table 2.

Responses to the scenario were coded holistically, since an individual progresses through perspectives developmentally [30]. With an individual only being able to express one perspective in their response, it makes sense to code the response as a whole [53]. To code responses, two researchers reviewed the codebook and trained on six responses together. Next, the researchers independently coded 15 (about 10%) of the remaining data set to attempt inter-rater reliability using Cohen's Kappa (κ) [54]. An acceptable range for IRR using Cohen's Kappa is above 0.8 [54], which was not achieved after the first round of coding. Researchers met to reconcile differences in codes, then individually coded another 15 responses in a second attempt to achieve IRR. This time an acceptable Cohen's Kappa was achieved ($\kappa = 0.90$), meaning the first researcher was able to code the remaining responses on their own.

Binning Participants

To answer RQ1 – *What differences exist between chemical engineering students' & experienced practitioners' perspectives when making process safety judgments* – participants were unblinded and reassigned to their group (student or practitioner). Student responses were analyzed for similarities and differences within their perspectives and compared to the perspectives of the practitioners.

To answer RQ2 – *What differences exist in perspectives based on participants' skills acquisition level?*— participants were further separated into their skills acquisition level based on their level of experience, which was found through a literature search of skills acquisition levels in clinical nursing [55]-[57]. Novices have been defined as individuals in their first year of education [55], which were not included in this study. Advanced beginners can include newly graduated students [55], which in the context of this study, represents the chemical engineering students in the process safety course with no experience. Individuals have been found to move into a competent phase after one to two [55] or one to three [56] years of engineering experience. In the context of this study, this includes undergraduate students with an engineering internship or co-op, and practitioners who have worked in engineering roles tied to process safety for less than three years. Proficiency is a transitional phase from competent to expert, which is difficult to define by years of experience. Benner et al. [57] believed proficiency could occur after at least two years in a specific field, but also found the competent phase to last three years, and expert to begin after five [56]. From this, it was interpreted that proficiency could occur after 2 years in a process safety specific role, or between three and five years of engineering experience. Finally, expertise occurs after five years of experience, and once they are recognized as an expert in that field by their peers [57]. In the context of this study, these were practitioners who worked at least five years in a process safety specific role.

Table 2: Perspectives codebook *[48]*

When responding to process safety scenarios, participants answered from a(n)…		
Code	**Definition**	**Examples**
None Perspective	Participants are unable to articulate a reason for their response. They may not recognize situational elements, however, if they do they do not understand how the elements would impact their judgment. They are following rules or instructions given to them by someone in power.	"I think I would go option B [Int: Okay, why do you say that?] I don't know that I see a reason not to. [I] feel like if you really don't have time, you could like, you know you don't have to go, but you can always like reschedule."
		"So I was, I was thinking about just like the strict deadline information, but I think it really depends on the situation... But it, I guess what i'm trying to say is that like, maybe there's like situations where, like having it one day late might not be too serious, and if they do realize that they don't have enough time, it might as well just give them enough time to kind of finish it by tomorrow."
		"I would probably go with that, because I've had a lot of situations where I've had strict like deadlines, and I'd be like 'Oh, I'm not able to finish this,' and surprisingly, a lot of my professors would be like, 'Oh, you can have like a little more time.'"
Chosen Perspective	Participants choose a plan or perspective that prioritizes an element while deprioritizing others. They will identify criteria that needs to be met for a decision to be made. They may rely on experience similar to the situation that supports their judgment.	"But if I was just about to go home, then I can just say twenty more minutes and talk to you. [Int: Okay,] Like not that hard, and that's a way it's like interpersonal relationships. There's like nothing that's not taking away anything for me except my time, which I think I said, I don't really care about."
		"Well, yeah, it kind of depends on what Charles is doing, who Charles is. If Charles is another hourly worker, I might choose B. If Charles, you know, Charles is on the same shift as the as the person asking I might say B. But if he's not, I would go ahead and take a look. Okay."
		"The reason behind that is job. Really, the new job really hasn't quite started up yet, and I'm it's very likely I'm not that busy yet, and I think that I'd like to. It's it looks like one of my engineers, yeah, he wants to talk about something. So I'll give him a chance to get to know me. Okay, develop a relationship."
Experienced Perspective	Participants are able to identify the solution to the problem without prioritizing elements or meeting criteria. They are able to break the problem into sub-cases and have a solution for each one. They rely on previous experience to support their judgments.	"And I would say, if, see when we worked, injured people came above everything. And we had plant managers who got terminated because of issues with people getting hurt, so that one's top. But I would say you could also be pushing through the night as long as you don't work too many hours without those 2 people. And you still could have [them] as your top priority. Getting my 2 employees well, first you go get them medical attention. But you can still work through the night without them. so it isn't like a A or B you can do A and B at the same time."
		"But I, I personally wouldn't stop there. I understand that when the units running it's affecting profit. If it's worth enough money. Then Wanda's job is to go get any additional resources. So I think these types of conversations, I look at a very material balance kind of level. If you need, If you need 10 people to run your unit and you only have 8 you are missing 2. That's the balance. And if you, and it's dangerous to try to start up understaffed. So if your organization thinks it's so important, they need to go find other staff who can help you get the unit up and running? If not, the answer is, it's gonna take as long as it takes to do it safely. And here's why I think that's sort of the line I would always draw."

Quality in Data Analysis

This work used the Q3 framework to ensure validity when collecting and analyzing data [58], [59].

Procedural Validation

As the data collected for this study was collected as part of a previous research project, this study did not use a protocol that was developed with the intention of capturing perspectives or modeled off the Dreyfus Skills Acquisition model. However, all interviews across both cohorts used the same protocol, which was able to capture their perspectives while responding to a process safety scenario. Additionally, only responses from participants prior to interviewer prompting were analyzed to avoid potential influence and keep protocols consistent. When handling the data, procedural validation was ensured by only using parts of the interview responses where the Dreyfus Skills Acquisition model could be applied. The first half of the interview, where participants were asked to rank six process safety criteria, was not included in this study because the Dreyfus Skills Acquisition model would not apply to their responses.

Communicative Validation

When interviewing participants, interviewers all read from the same semi-structured interview protocol to guide the conversation and provided all participants with a visual guide. Participants were encouraged to ask clarifying questions about the scenarios or responses, to which the interviewer would respond without changing the meaning of the scenario or responses. Additional context and probing questions were only given or asked after the participant had given their initial response. Analysis of this data identified the participants' perspectives when responding to the process safety scenario, which helped in determining if responses are instructional and rule-based, or if participants were using situational elements to make and justify their judgments.

Process Reliability

All interviews were conducted and recorded on Zoom, which were later used to clean and verify transcripts. Two researchers were present at each interview – the first would lead the discussion, and the second would take notes, and assist in identifying probing questions for the first interviewer to ask. All of this information was recorded in an audit document, which was shared with the research team which tracked lead and secondary interviewers for each interview, the transcript review process, and deidentification procedures. Participants were also assigned a pseudonym, which the researchers eventually became familiar with. To avoid bias in data analysis, pseudonyms were replaced with numerical identifiers, which were hidden and shuffled when coding the data.

Results & Discussion

This study sought to determine differences in students' and practitioners' perspectives when responding to process safety scenarios by comparing their process safety judgments and the reasoning that surrounded them. Additionally, it aimed to identify any nuanced differences occurring between skills acquisition levels by binning students and practitioners based on their level of experience. The following sections summarize major findings from these analyses, what could be the cause for any differences observed, and the implications of these findings.

Students' Perspectives vs. Practitioners' Perspectives

To answer RQ1, the percentage of Perspectives codes used by students and practitioners were found. This analysis was chosen because it allowed for a fair comparison across the different sample sizes and accounted for the scenarios that were removed during the data cleaning process. Results for students and practitioners Perspectives codes are provided in Table 3.

Table 3: Students' and practitioners' Perspective codes

		Perspective Code		
		None	***Chosen***	***Experienced***
Students (n=12)	***Total # of codes***	20	25	11
	% code used	35.7%	44.7%	19.6%
Practitioners (n=15)	***Total # of codes***	6	28	38
	% code used	8.3%	38.9%	52.8%

Students accounted for a majority of the None perspectives because they struggled to articulate a reason for their response. Often, students would not select responses if they believed they were rude or harsh, instead of considering the situational elements surrounding the judgment. For example, when responding to scenario about an injured employee (presented earlier in this paper), Delta said *"That, like [choice] A, sounds really harsh and like, I just don't think I would ever say something that kind of like. I'm pretty cold, but then [response] B is too soft. I think."* When responding to a different scenario about pushing production through the night while short two employees because they were injured, Kilo answered *"I guess, it's kind of like the second one just sounds like a little rude... [response] B like, I guess. Sounds a little sassy with like profit can wait…"* Students also struggled to find a reason why they should not say no or identify situational elements that may make them choose the other response. For example, when responding to a prompt about going out to lunch with an employee, Aaron said *"I think I would go option B…I don't know that I see a reason not to,"* similar to Kilo's response, *"Because I feel like if you just started a new position, you want to get to know people. So I can't imagine, a reason or like, I want to be able to make the time."*

Students also fell back on previous instruction or rules when they weren't sure how to navigate a process safety scenario. This information came from a variety of areas, such as the classroom, or prior internships. For example, Elephant chose to help their employee review overtime sheets instead of delegating the job to a veteran employee so they could leave work on time, saying *"I'd be happy to share and just be open with that. That is something that I've learned through my management classes and my industry experience."* Students also relied on procedures or protocols that were mentioned in the scenarios, like Bravo who said *"I say, you give him as much time as they need, but hopefully as much time as they need is protocol. So, like ideally, those two should not be different."*

Practitioners hardly showed a None perspective, and would support their Chosen and Experienced perspectives with experience. Additionally, practitioners were able to describe the potential benefits of their judgments or hypothesize what could go wrong. Practitioners with Chosen perspectives would clearly prioritize or deprioritize situational elements of the scenario and would use their personal experience to support their judgements. For example, Kingfisher responded to a scenario where an employee was hurt by reflecting on their own previous experiences with injured employees, *"I've been there before, and they've, you know, it's happened before. Badly burned. It shouldn't have happened. But* *still you have to let that person take time."* When responding to a different scenario about extending or holding firm on a production report deadline, Flamingo supported their judgment to stick to the deadline by saying:

> *"So when I give people in my organization deadlines, you know. Sometimes it will literally be because a report needs to be filed by a court like, there's no wiggle room. Other times it's because I want 24 hours to be able to look something over before it gets passed on to someone else."*

Practitioners with Experienced perspectives would also rely on previous experience when responding to process safety scenarios to support their judgments. When responding to a scenario about an employee being burned by steam, Flamingo responded to the prompt about the proper amount of time the employee should have to recover by saying, "*How much time someone has off in response to an injury is like an HR thing… A plant manager is not in control of how much time someone takes off for an injury."* Craft responded to a different prompt about pushing production through the night while down two injured employees by relating the process safety scenario to a dilemma they were currently facing at work, *"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 over time with other operators."*

Practitioners would also describe the benefits of their responses, or hypothesize what could go wrong to support their judgments. Dingo identified the benefits of working a little longer to help an employee with their overtime sheets, stating

> *"I always feel that it's very helpful to again, work with people, show them how to do things…And you end up usually with a much better product when you're all done, when everyone is on the same page of what to expect and how to do it."*

Consequently, Bingo describes that delegating the work will allow them to *"finish out tasks, that will kind of help me make sure I'm not staying too late and get out [at a] reasonable time."* Other practitioners would theorize potential drawbacks of responses to support their judgments. For example, Crane chose to extend the production report deadline for their employee, stating *"the worst case, you can make somebody rush it*." Crane goes on to say that they would rather the employee take their time completing the document then rush to get it done, in fear that *"you're always [going to] miss something. If you try to push somebody very quickly."*

Overall, students struggled to articulate reasons for their responses, and often relied on instructions, causing them to mostly hold None or Chosen perspectives. Practitioners were able to rely on experience and describe potential benefits and drawbacks of their responses, which was indicative of Chosen and Experienced perspectives. Students may be having None or Chosen perspectives because they are not being exposed to enough real-world problems with situational elements that reflect the complexities of process safety judgments. In academia, engineering students typically learn complex concepts through decontextualized textbook problems that do not reflect the complexities of real-world engineering problems [25], [43], [60]. With limited exposure to contextualized, real-world problem solving, students are unable to identify situational elements in a process safety scenario, or understand how they would influence their judgment, causing them to fall back on rules or instructions learned in class [30]. Practitioners' experience with contextualized, or ill-structured, problems has exposed them to enough situational elements that allows them to recall experiences that may support their judgments or hypothesize potential benefits and drawbacks. In later stages of skills acquisition, individuals have experienced so many judgments, they have built a repertoire of situational elements and discriminations that allow them to make judgments based on their previous experience [30], [55]. Additionally, practitioners solving ill-structured problems triggers intuitive reasoning that may help them assess the present situation, and predict future outcomes [61]-[63].

Perspectives Based on Skills Acquisition Level

To answer RQ2, the same method to find the percentage of Perspectives codes was utilized, however, percentages were calculated across skills acquisition level. This analysis was chosen because it allowed for a fair comparison across the different sample sizes and accounted for the scenarios that were removed during the data cleaning process. Additionally, there were both students and practitioners in the Competent level, which were separated for this analysis to reflect the differences observed earlier between students and practitioners. Results for Perspectives codes in each skills acquisition level are provided in Table 4.

Table 4: Perspective codes in skills acquisition level

			Perspective Code		
			None	**Chosen**	**Experienced**
Students (n=12)	Advanced Beginners (n=6)	*Total # of codes*	9	14	4
		% code used	33.33%	51.85%	14.81%
	Competent Students (n=6)	*Total # of codes*	11	11	7
		% code used	37.93%	37.93%	24.14%
	Total Students	***Total # of codes***	**20**	**25**	**11**
		% code used	**35.7%**	**44.7%**	**19.6%**
Practitioners (n=15)	Competent Practitioners (n=4)	*Total # of codes*	1	5	11
		% code used	5.88%	29.41%	64.71%
	Proficient Practitioners (n=3)	*Total # of codes*	5	6	4
		% code used	33.33%	40.00%	26.67%
	Expert Practitioners (n=8)	*Total # of codes*	0	17	23
		% code used	0.00%	42.50%	57.50%
	Total Practitioners	***Total # of codes***	**6**	**28**	**38**
		% code used	**8.3%**	**38.9%**	**52.8%**

Advanced Beginners

All Advanced Beginners were students (n=6). When Advanced Beginners would show a None perspective, they struggled to find a reason to say no and were concerned about their tone. Interestingly, Advanced Beginners used Chosen perspectives more than any other skills acquisition level (51.85%) and would often identify criteria that would have to be met in order for a response to be chosen, similar to an "if/then" statement. For example, Delta responded to the scenario about helping an employee with their overtime sheets by reasoning that *"If I was busy, then I would do that [delegate work]. But if I was just about to go home, then I can just say twenty more minutes and talk to you."* Similarly, when responding to the scenario about a deadline extension, Golf said,

> *"I think this answer would largely depend on the type of... how I know this employee, how I know that their work ethic is. Like, if this is the first time that they're asking me for a deadline extension, then I would be able to do that. But if it's a consistent thing, they're constantly asking me about extending a deadline, then I have to put my foot down at a certain point, and I would have to answer B."*

In these responses, Advanced Beginners are beginning to determine which situational elements are salient to the scenario – Delta based their response on the time they had available, and Golf wanted to know more about the employee's reputation. However, there is not a clear prioritization or deprioritization of situational elements that is clearly indicative of a Chosen perspective. Some Advanced Beginners with a Chosen perspective were able to prioritize a situational element, and interestingly, this element was commonly relationships. When responding to the scenario about getting lunch with an employee, Lemon responded *"I was saying, like relationships are important, and I think as a leader like having that relationship with your employees are very important."* It's possible that Advanced Beginners are prioritizing relationships due to the emphasis on teamwork and communication in their courses, which relies on the relationships they build with their peers [64]. However, it's been noted elsewhere that engineering students do not fully recognize or understand the influence of relationships when making judgments [50].

Competent

Competent students (n=6) were separated from Competent practitioners due to the aforementioned identified differences between students and practitioners. There were not many similarities between the two cohorts (competent students and competent practitioners), which supports Dreyfus' main idea that expertise is achieved through experience [30]. Of all Competent individuals (students and practitioners), Competent students accounted for 11 out of the 12 None perspectives, and had many similarities with the Advanced Beginners – they were concerned with their tone, and they struggled to find reasons why they would not choose their response. Competent students showed a Chosen perspective less than Advanced Beginners (37.93%) but were very clear in the prioritization and deprioritization of the situational elements. Additionally, Competent students moved away from prioritizing relationships, and instead focused on elements like employees, their manager, and safety. For example, when responding to the scenario about pushing production through the night, Echo replied, *"I would respond with B, because this is the response that put safety first. And like you might lose some profit, but you would lose a lot more if there were a lawsuit involved,"* clearly prioritizing safety, and recognizing that profit is not as important in this case. In a different scenario, Hotel responds to a scenario about an employee getting injured by saying *"[In] the case the head chief ask you, and a lot of the times, the head chief has a lot of work to do. So just a quick like 'I'm following protocol. Thanks for checking in,'"* which prioritizes what their boss wants to hear. It's possible this change is occurring due to the experience these students gained from their internships or co-ops. In these positions, they would have been exposed to situational elements like safety, managers, and employees, which would begin to develop their perspectives [30].

Competent practitioners (n=4) accounted for one None perspective, and five Chosen perspectives. However, one practitioner was responsible for four out of the five Chosen perspectives, so only generalized themes from Competent practitioners that showed Experienced perspectives were analyzed. Competent practitioners were able to forecast the outcome of their responses, however, they specifically focused on what could go wrong. When asked if they would get lunch with their employees, Newt responded

> *"My answer would be if I had time, sure, I'd love to get lunch with someone and get to know them, plus I get lunch. But you know…sometimes, getting lunch implies that we're possibly leaving the facility and sometimes, even if you're not busy, there's a situation going on where you can't not be there because you could be needed. You know, production isn't in a steady state. It's not in a nice flow. And so basically something could come up where I could need to step in. And I don't want to be off-site."*

Although these practitioners are able to forecast their outcomes, a skill gained through experience and engineering intuition [63], it seems they are doing so to avoid potential consequences. Individuals learn from the positive and negative outcomes of their judgments, and use them to strengthen and develop their perspectives [30]. It's possible that Competent practitioners who are beginning to show Experienced perspectives are more likely to recall their previous negative outcomes when supporting their response, instead of positive outcomes.

Proficient

Proficient practitioners were the smallest cohort (n=3) but were nearly evenly distributed across the three perspectives. Out of the practitioners, Proficient individuals had the most None perspectives (33.33%), with each practitioner having at least one None perspective. When showing a None perspective, Proficient practitioners' responses were often brief and identified one or two situational elements. For example, Ostrich supported their response to get lunch with their employee by saying *"because they referred to me as chief."* Similarly, Ibex supported their response to help an employee with overtime sheets by saying *"You want to have a little bit of personalness with your people."* These responses could indicate that different from the students with None perspectives, Proficient practitioners with None perspectives are able to articulate their response but chose not to elaborate. However, more research is required to support this claim.

Proficient practitioners with Chosen perspectives would still prioritize and deprioritize elements, similar to students, however, they would support their responses with experience. Ostrich supported their response to the extend a deadline by saying *"I manage one project at my current job and people, it has a lot of small reports that we turn in… I just push deadlines all the time. But yeah, that's not a big life or death thing. It's a super small project."* This theme carries into their experienced perspectives, where Proficient practitioners would rely on experience to support their judgments. Ibex emphasized the importance of safety in the scenario asking about pushing production through the night by recalling *"…when we worked, injured people came above everything. And we had plant managers who got terminated because of issues with people getting hurt, so that one's top."*

Overall, Proficient practitioners did not show consistency in the perspectives they would use, being dubbed the "wild card" of the study. This could indicate that there is more fluctuation occurring in this transitional stage than just a shift from Chosen to Experienced. Similar to the "hierarchical integrations" of Kohlberg's moral stages [65], this could mean that individuals with Experienced perspectives are still in the process of reconciling lower level perspectives, like None and Chosen.

Expert

Expert practitioners (n=8) shared attributes with all other skill levels, further reinforcing that progressing through perspectives could be a "hierarchal integration" rather than a linear process. Expert practitioners with Chosen perspectives would often prioritize relationships, similar to Advanced Beginners. They would forecast to determine the positive outcomes of their judgments, reflecting Competent practitioners hypothesizing negative outcomes. And they used experience to support their responses, similar to Proficient practitioners. Uniquely, Expert practitioners with a Chosen perspective would not deprioritize situational elements but would rather acknowledge the importance of the response they were not choosing, and attempt to make up for any shortcomings. When asked to get lunch with an employee, Bingo supported their response to say no by saying *"I'm talking to my boss right now. Can't do it right now, but long as you're able to meet up shortly. I can do it."* Lynx chose to prioritize the safety of their employees rather than pushing production through the night but acknowledged *"That doesn't mean that I won't do whatever I can to restore production. That is important as well."*

Most interesting and unique to Expert practitioners with an Experienced perspective was the willingness to go the extra mile to prevent a repeat of the incident, avoid further injuries, or care for the employee. This is reflected in Lynx's response to the scenario where an employee was hurt:

> *"I followed protocol, and something happened. So there's no problem there. I would not take that perspective. We have to be evaluating our protocols and making sure that they don't lead to issues and including, did we overlook some safety concern that we didn't see as part of the protocol? In which case we would have to go back and reevaluate the protocol in the first place. You can't leave something uncovered. And it has happened that we have failed to see something embedded in our protocols that led to the problem in the first place. In which case we have an obligation to update the protocol. So that we don't see this happen again."*

In this response, Lynx goes beyond just caring for the employee or ensuring the protocols are complete. They identified that there could have been an error in the protocol, that led to the employee getting injured, and the responsibility they have to evaluate and update those procedures so an accident like this does not happen again. This level of problem-solving and foresight could be attributed to the amount of experience Experts would have solving "ill-structured" problems. Ill-structured problems possess multiple solutions that are found through different combinations of concepts, rules, and principles [43], and trigger intuitive reasoning [61], [62]. With enough experience solving ill-structured problems, individuals are eventually able to move away from analytic reasoning and into intuitive thinking that is characteristic of the Expert skills acquisition level [30], [55]. Specifically, engineering intuition has been reported to allow individuals to assess present situations or predict future outcomes by leveraging their previous experience [63], thus setting Experts apart from other practitioners.

The main takeaways from this analysis are the impact that experience plays in developing an individuals' perspective, and that the progression of perspectives appears to be following a hierarchal integration. Experience set Competent students apart from Advanced Beginner students in how they were able to form their Chosen perspectives, and the situational elements they were able to identify. Competent practitioners hardly used experience to support their responses, while many Expert practitioners were able to forecast actions that would prevent further incidents from occurring. The progression of perspectives also appeared to be a hierarchal integration, with individuals moving between perspectives rather than residing in the one that represented their skills acquisition level (e.g. Advanced Beginners – None). This was most apparent in the Proficient phase where perspectives were nearly evenly distributed, indicating that there may be more occurring in this transitional phase than just a shift from Chosen to Experienced.

Conclusion

This study investigated the difference in students' and practitioners' perspectives when making process safety judgments, and the differences in perspectives between skills acquisition levels. To complete this study, responses to process safety judgments from 12 chemical engineering students and 15 practitioners were collected, holistically coded for a None, Chosen, or Experienced perspective, and compared to determine differences between the cohorts. This study found that students struggled to articulate reasons for their responses, or relied on instructions, which could be due to the well-structured, decontextualized problems that academia favors [43], [45], [60]. Practitioners were able to rely on their experience and describe potential benefits and drawbacks of their responses, which could be indicative of the engineering intuition they've built after so much experience with ill-structured problems [61]-[63]. Differences between skills acquisition levels were more nuanced, but emphasized the importance of gaining experience to recognize situational elements, and the need for students to solve more ill-structured problems in class [61]. Additionally, it was determined that the development of perspectives could be a hierarchal integration instead of a linear progression, meaning individuals at higher levels (Experienced perspective) are still able to recognize and understand lower levels (None perspectives).

This study supports the need for more complex, ill-structured problems in the process safety classroom that demonstrate the impact of students' judgments on situational elements beyond just safety, also integrating such as relationships, production, and time. Academia favors well-structured problems, where students are expected to find one solution using one method [62], which may be leading to a reliance on procedures when facing real-world problems. Exposure to ill-structured problems through interventions using game-based strategies [32], [51], [66], or immersive case studies [48], [67] allows students to make realistic judgments in controlled environments, which may improve their ability to recognize situational elements that often influence process safety judgments. Additionally, other studies are currently investigating the potential of integrating "engineering intuition" into the classroom [63], [68], [69], which has the potential to develop more skillful engineering students who have a more experiences, intuitive understanding of real-world problems [70]. Overall, it is important that educators familiarize students with the situational elements associated with process safety and prepare them for the complexity of judgments they will face in industry.

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