FACULTY PERCEPTIONS OF PROCESS SAFETY JUDGMENT CRITERIA: A PILOT STUDY

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MOTIVATION

While the importance of process safety education is undisputed, it remains an area for improvement in chemical engineering education. In the 20 years it has existed, the United States Chemical Safety and Hazard Investigation Board (CSB) has investigated more than 130 incidents and issued over 900 recommendations for improving process safety in the chemical industry.[1] These incidents have resulted in injuries and deaths, environmental impacts through the release of dangerous chemicals into both the air and local water systems, and significant financial impacts that have harmed the bottom line of companies' budgets.[2-4] For this reason, accrediting bodies and professional societies associated with chemical engineering have sought to build and reinforce the need for process safety culture throughout the undergraduate curriculum and into professional development. In 1985 the American Institute of Chemical Engineers (AIChE) formed the Center for Chemical Process Safety (CCPS) in response to the Bhopal, India toxic release of methyl isocyanate. The CCPS was developed to promote process safety as a key industry value and to work with experts in the field to develop educational materials to support a culture of safety.[5] Subsequently in 2011, ABET required that chemical engineering undergraduate programs include potential hazards associated with chemical engineering processes as part of the curriculum, thereby closing the loop to ensure a continuing emphasis on process safety from the undergraduate curriculum up into industry.[6]

Although process safety training and educational interventions have been in place now for several years, oftentimes the emphasis of these sessions is on approaches to improve the safety of the design [7] as it aligns with how faculty members may have been exposed to or trained about process safety within their own career. Safety by design is a critical component of process safety incident prevention, but it falls short by not addressing the circumstances that lead to many of the identified incidents. These incidents can largely be traced to judgments made in these process safety contexts. It is important that faculty members are aware of and understand the complexity associated with these process safety judgments so that they can structure the undergraduate curriculum with this emphasis. For instance, in the recent 2018 Kuraray Pasadena ethylene release and fire, management had a policy in place that non-essential workers should not be in the area of equipment when it was having ethylene reintroduced into the system. However, management had not officially specified the range or zone around pieces of equipment that should be evacuated during these situations. In this particular situation, the majority of the personnel injured, 23 in total, were non-essential workers who could have been spared injury had they been removed from the location of the reactor that was being charged with ethylene at the time of the occurrence.[2] Similar process safety judgments were also responsible for events that led up to the Loy Lange Box Company pressure vessel explosion in 2017. In this particular case, the company had not been conducting appropriate maintenance on its pressure vessel, and although corrosion was noted in the vessel as early as 2004, no steps were taken to address this corrosion, leading to its ultimate failure nearly a decade later.[8]

These process safety incidents underscore the complexity of process safety judgments that stem from the need to balance the prioritization of competing criteria (e.g., safety and production). Each incident is ultimately the result of individuals' choices that require exercising judgment in weighing competing criteria and can be susceptible to human error. Neglecting to specify safety protocols or conduct appropriate maintenance, for example, demonstrates prioritizing time or production over safety.[2, 8] This devaluing of safety at that moment is not necessarily a character flaw of the engineer, but rather a reflection of the complex competing demands they are faced with daily. The pressure of performance demands, relationships, or other factors can inadvertently outweigh safety when judgments are made in real time. We believe the susceptibility of these real-time

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judgments to human error is further compounded by a potential gap between how individuals believe they will approach judgments versus how they actually make judgments. While safety is paramount, we need to acknowledge the additional considerations (or criteria) practitioners are weighing during critical judgments. Prior research identified leadership, production, relationships, spending, and time as criteria that often compete with safety in chemical engineering practice.[9]

We argue that undergraduate education does not adequately prepare students for the complexity of real-time process safety judgments because curricular emphasis is on safety by design through mechanisms such as process hazard analysis.[10-11] As mentioned previously, the predominance of this approach may stem from how faculty themselves were trained on process safety or from a lack of awareness of how criteria that compete with safety can significantly impact process safety judgments. A safety by design approach does not consider the pressures of competing criteria on real-time process safety judgments and perpetuates the narrative that safety will always remain first. Our work seeks to unpack the relationship between individuals' espoused (stated) beliefs and their (simulated) behavior when approaching process safety judgments and explore the use of a digital process safety game as an intervention for exposing individuals to the complexity of these judgments. In this pilot study, we focus on faculty's perception of the relevance of specific competing criteria in process safety and their experience of a brief group play-through of the digital process safety game. Faculty are a critical stakeholder in adopting new curricular interventions, so characterizing how faculty experience the intervention will better support its refinement for future implementations in the classroom. Our interest in studying faculty is further motivated by the documented resistance to curricular change in higher education [12-14] and the subsequent need for faculty support in adopting new practices.[15]

LITERATURE REVIEW

Prior work has shown that engineering students believe that their process safety judgments consistently prioritize upholding safety.[16] This belief disregards the complexity of real-world process safety judgments and parallels literature on ethical dilemmas that demonstrates how individuals are unable to recognize the ethical dilemmas embedded in everyday judgments despite believing that they will.[17] Experiences are a major contributor to the formation of beliefs;[18-19] students' process safety experience is often limited to classroom experiences that are unable to authentically represent process safety in industry. These limited classroom experiences are likely an important contributing factor to their oversimplified beliefs.[18-19] These classroom experiences are curated by faculty, emphasizing the important role of faculty in the formation of students' beliefs and subsequently their position as key stakeholders in addressing the beliefs-behavior gap in process safety judgment. Our work focuses on faculty reactions to game-based learning tools that they can use for developing individual awareness of the beliefs-behaviors gap in the context of process safety. The game serves as a means of simulating industry experience for participants, allowing them to more critically approach process safety judgments through heightened awareness of the competing criteria that may be involved in these judgments and creating a reference for interrogating beliefs around process safety judgments.

Judgment and Beliefs

Despite their known importance, human factors and decision making continue to be understudied components of process safety.[20-23] Human Reliability Analysis is an approach to risk-assessment that aims to address the human factors in process safety and other contexts,[24-25] but this approach is vulnerable to the same human factors it purports to analyze.[26] The limited progress in this area of study underscores the complexity of real-time human judgments. Judgment is exercised (the process) to arrive at a decision (the outcome) and susceptible to external pressures, including demands on cognitive load.[27] Humans are subconsciously primed to take the path of least cognitive load, which may mean acting without deeply thinking things through [28-30] when making a judgment. The taxing role of judgment on cognitive load may offer some insight as to why an individual's espoused beliefs about how they will approach judgments do not always align with their behavior in real time.[17]

Implicit bias is a construct where this tension between beliefs and behavior has been well documented.[31-33] The work in implicit bias further highlights the difficulty in changing beliefs and supports the notion of raising awareness of the gap between beliefs and behavior as an intervention for promoting conscientious judgments.[31-33] This awareness is particularly valuable in the context of process safety, where a poor judgment can have catastrophic consequences.

Game-Based Learning

Raising awareness necessitates experiences to draw upon for discussion, but real process safety contexts are difficult for faculty to replicate in the classroom. One tool that can be used to help address this issue of replicating process safety conditions for the training of undergraduate engineering students is the use of digital games. Digital games are beneficial as they provide a number of different advantages that cannot be reproduced in a normal classroom environment. In particular, games provide an avenue for individuals to become immersed in the situations they are confronting.[34] This occurs due to a combination of game-based features, including their graphics, realism, and their narrative.[35-37]

One form of immersion, sensory immersion, is particularly beneficial for the purpose of providing process safety training as it affords the opportunity to provide an environment that is a high quality replication of an actual environment and encourages the participant to gain a sense of presence within the context.[38]

Another benefit of games as a tool for process safety training is their ability to provide authentic learning environments for participants.[39] As described by Squire,[40] games are powerful in that they create environments for individuals that allow them the benefit of both "being" and "doing," which are unique from other forms of education. In other words, they are able to provide a safety net where individuals can test out decisions or choices and receive feedback on the potential outcomes that would not be possible for situations that risk safety or the environment.[41] The ability to provide this testing ground is different from case studies where the instructor framing can lead students to identify the correct approach.[42] For this reason, case studies do not yield the same opportunity to test out multiple approaches that game play offers.[42]

Contents Under Pressure (CUP) is a game that offers the opportunity for participants to experience firsthand how judgments they make relative to competing criteria will influence the operation of a chemical plant. The game follows a 15-day narrative where the participant is placed in the role of a senior plant engineer and is responsible for a team of operators. As part of their position, they report to not only their boss but also a safety inspector who drops in to visit the plant.[43] Research conducted with CUP has shown that it provides an environment that can more accurately reflect students' responses to process safety judgments and can allow students to recognize the complexity that is associated with these types of decisions.[16, 44] As a part of the undergraduate curricula, CUP can help faculty mitigate students' beliefs-behaviors gap in process safety judgments by serving as a tool for proactively surfacing the existence of the gap. Engaging in the same critical reflection of their own beliefs versus behavior through CUP game play may serve to remind faculty of the complexity of process safety judgments and allow them to better address that complexity in their classroom instruction while still promoting safety.

CONCEPTUAL FRAMEWORK

This study leverages a conceptual framework that was developed to address competing criteria that are relevant to process safety judgments.[9] The conceptual framework defines six competing criteria: leadership, production, relationships, safety, spending, and time. The selection of these specific criteria was made as a result of their identification as important in judgments made in a variety of other professional contexts.[20, 45-48] For example, in a study by Encinosa and Bernard (2005) in the healthcare industry, they found that there was a significant relationship between the profit margins of a hospital and the occurrence of patient safety-related events.[49] It was observed that patients at hospitals within the highest profit margin quartile were 12% less likely to experience a patient safety event than those treated at the lowest profit margin quartile hospital.[49] These results indicate how criteria such as spending can compete with other criteria, such as safety, when making judgments in a professional setting.

Although the conceptual framework was developed on the basis of the use of these criteria in judgments in other professional contexts, these criteria have also been found to be relevant in process safety judgments. Review of case studies shared on the Chemical Safety Board website found that many of the incidents that have occurred can be related to juxtaposition of the aforementioned criteria. For instance, in the 2018 Ethylene Release and Fire at Kuraray America, critical choices were made leading up to the incident, such as not opening the pressure relief valve all the way, not recognizing the difference in pressure rating of reactors on site, and lack of communication between operators running the startup of the reactor, that led to this incident ultimately injuring 23 employees.[2] In this case, both productivity of the plant and leadership were factors that juxtaposed safety in the judgments that were being made. Specifically, the choice to not open the pressure relief valve the entire way was made due to a concern about exceeding environmental limitations and the individual being distracted by other on-going startup activities occurring at the plant on that day. Another example that shows the juxtaposition of spending and safety is the Philadelphia Energy Solutions Refinery Fire that took place in June 2019.[4] In this case, one of the leading factors contributing to the incident was a pipe elbow that corroded faster than anticipated, leading to a rupture releasing a vapor cloud into the refinery. The type of pipe that was used for this part of the plant did not meet the current day safety standards but was never replaced despite 40 years of service. In addition, it was observed that Philadelphia Energy Solutions, and the company that owned the plant previously, never performed carbon steel piping inspections to identify if there was any corrosion taking place that could lead to an unexpected rupture in the piping system, potentially due to financial pressures.[4]

These examples demonstrate the complexity of process safety judgments and the need for understanding the varying criteria that impact these judgments to help mitigate the possibility of future chemical safety incidents in professional practice. The ultimate goal of our work in this space is to bring awareness to the complexity of these judgments, and in particular the gap between individuals' espoused beliefs and enacted behaviors. We believe CUP is a viable tool for surfacing this gap and creating a tangible experience in which to discuss it with engineering students.

As the first gatekeepers of process safety knowledge for future practicing engineers, faculty are an important stakeholder in achieving this goal. Thus, in this work we are interested in characterizing faculty perceptions of the relevance of the process safety criteria, and whether CUP game play affects faculty rankings of the relative importance of the criteria to support refinement of the intervention for broader use.

RESEARCH QUESTIONS

1. *What relevance do chemical engineering faculty ascribe to the process safety criteria in the context of process safety instruction?*
2. *How do chemical engineering faculty rankings of process safety judgment criteria change as a result of exposure to the group play-through of a portion of a process safety decision making game?*

METHODS

The following sections outline the sample for our study, the approach to data collection, and the analysis that was conducted.

Participants, Recruitment, and Sampling

We sampled participants from attendees of the ChE Summer School (CHESS) who took part in a process safety workshop where the Contents Under Pressure game was played. There were eleven participants in attendance at the workshop, of which a total of nine faculty members consented to participate in the study. Most (six) participants had not taught process safety before. One-third of the population (three participants) was about to start their teaching careers in Fall 2022, while one person had taught for 1-2 years, one for 3-4 years, two for 5-6 years, and two for 7+ years. Because CHESS is aimed at early-career faculty, the majority of the sample (seven participants) having six or fewer years of experience is expected.

Female faculty are overrepresented in our sample compared to the US population of chemical engineering faculty, as well as the participants of CHESS. Nationally, female faculty represented 21% [50] of chemical engineering faculty in 2019. At CHESS in 2022, female faculty made up 38% of the population and male faculty 61%.[51] Female faculty are 44% (four participants) of our sample and represented in equal numbers as male faculty. Non-binary/third gender faculty are also overrepresented in our population (11%, one participant) compared to the CHESS population (1%).[51] No data are provided on national non-binary/third gender faculty representation, so we cannot comment on how our sample compares in that respect.

Chemical engineering specific data are not available for faculty position types or ethnicity, but we can compare our sample to US engineering faculty as a whole in these categories. Non-tenure track faculty are slightly overrepresented in our sample compared to the US engineering faculty. Again from Fall 2019 numbers, tenure track Assistant Professors outnumbered non-tenure track faculty (7,779 assistant professors, 6,284 non-tenure track faculty) in the US,[50] whereas in our population non-tenure track faculty (5 participants) outnumber tenure track (4 participants) by one. This overrepresentation of non-tenure track faculty also holds compared to the CHESS population, where 75% of participants are tenure track.[51] Comparing the ethnicity of our sample with the US engineering faculty, our sample has Hispanic/Latino overrepresented and Asian slightly underrepresented. In Fall 2019 Hispanic/Latino faculty made up 3.9% of U.S. engineering faculty [50] and comprised 11% (one participant) of our sample. This overrepresentation of Hispanic/Latino faculty likely reflects the similar overrepresentation of this group at CHESS, where 9% of the population reported Hispanic origin.[51] Asian faculty made up 28.7% of engineering faculty[50] and 34% of CHESS participants [51] but only comprise 22% (two participants) of our sample.

Data Collection

Data were collected through an online Qualtrics® survey administered in real time during the CHESS workshop. Data was collected in two parts: (1) after a brief introduction to the workshop but before game play (pre-CUP) and (2) immediately after game play (post-CUP).

In the first part of the survey, participants were asked to quantitatively rank the six process safety criteria from the conceptual framework as outlined in this prompt: "*How do you rank/order the criteria listed below as they relate to process safety decisions you would make in a chemical plant environment? The most important criteria should be at the top of the list and the least important should be at the bottom*." Participants were then encouraged to provide an explanation for their selection and any contextual factors that may have influenced this order. They were also asked to qualitatively share how relevant they felt the identified process safety criteria were to process safety instruction. After completion of these initial survey questions, participants were led through a portion of the CUP digital game on process safety.[43, 52] CUP was played as a group with the game projected on the front screen. For each scenario, participants were prompted to select one of the two options available and vote on the desired action as a group. The resulting effects of the choices were visible as the metrics at the top of the screen changed to reflect the group's decisions; an example of this game play is provided in a video elsewhere.[52]

After completion of 20 judgments in CUP, participants completed the second part of the survey. These additional

survey questions asked them to quantitatively re-rank the provided process safety criteria and qualitatively explain their ranking and whether they believed their beliefs about the role of these process safety criteria changed because of their participation in the game, along with an explanation.

Data Analysis

Descriptive statistics for faculty process safety criteria rankings were determined to identify the median rankings for each criteria for the entire sample (n = 9). As the ranking data was ordinal and not scale based, medians were selected rather than means to appropriately represent the faculty selections both pre-CUP and post-CUP. Due to the small sample size, we limited our analysis to descriptive statistics and effect sizes since any p-values obtained would not have sufficient power to be meaningful.[53] This approach aligns with current recommendations from the American Statistical Association that the p-value alone is not necessarily a measure of evidence pertaining to a hypothesis.[54] Due to the ordinal data obtained from the rankings and the small sample size, effect sizes (r) for pre-CUP, post-CUP, and changes in process safety criteria ranking were determined to provide insight on possible statistical implications of the results.[55]

Qualitative open-ended survey questions were analyzed for relevant themes through an inductive coding process. Both faculty researchers read all of the responses received and then compiled a list of identified themes. Subsequently, the open-ended survey responses were coded for these themes to determine their prevalence amongst the sample.

LIMITATIONS

There were a number of limitations that were encountered with this study and may lead to lack of generalizability and transferability of the results. The first limitation was the sample size. Although eleven participants attended the process safety workshop, only nine individuals were identified as faculty members and selected to consent to participate in the study. As a result, this limited our ability to analyze the data quantitatively since statistics on such a small sample size are limited in power.[53] Future research could expand upon these findings with a larger sample size to determine if any statistical differences exist. The small sample size also limits the transferability of our qualitative results. Additionally, faculty demographics of our sample were not typical for chemical engineering faculty and may have influenced the results obtained. Further limitations tied to the results of our study include that faculty may have felt the need to ascribe the relevance of the process safety criteria due to the setting of this study being conducted within a process safety workshop. Also, the faculty sample was only exposed to approximately 20 prompts in CUP that they played through collectively as a group. The brevity and group nature of the intervention may have limited its direct effect on criteria rankings. Lastly, this study is limited in its generalizability and transferability, as the sample of faculty members in attendance were a combination of junior ChE faculty members and ChE Summer School presenters from the US, thereby limiting its representation of chemical engineering faculty members as a whole in the United States.

RESULTS AND DISCUSSION

This study sought to obtain a better understanding of how chemical engineering faculty perceive process safety judgment criteria and whether their relative importance changes as a result of exposure to a digital process safety game. This section outlines the responses to the two posed research questions along with how the results are situated within relevant literature.

Research Question 1

The first research question this study sought to answer was "*What relevance do chemical engineering faculty ascribe to the process safety criteria in the context of process safety instruction?*"

Faculty participants in our sample described the six criteria as relevant to process safety instruction, suggesting that the criteria align with faculty perceptions of important components associated with process safety judgments. The specific question related to the relevance of the criteria was answered by seven of nine participants. Emergent codes were: explicitly relevant, implied relevant, and did not answer. Of these, five responses supported that the criteria were relevant (coded as explicitly relevant or implied relevant). Three responses explicitly stated that all criteria were relevant, one implied all were relevant by answering simply with *"very,"* and one implied they were relevant through a detailed explanation of the relevance of four criteria (safety, production, time, leadership). The remaining two participants did not address the question in their response (coded as did not answer), though one suggested the criteria were relevant but incomplete by responding just with *"pressure from boss or clients to produce more products is missing."* This response may suggest that perceived definitions of the criteria are not always consistent, as we would classify the participants missing criteria as being captured by leadership and production. This suggested difference in interpretation underscores the continued importance of defining each of the process safety criteria in classroom discussions.

The relevance participants have ascribed to the process safety judgment criteria further supports the applicability of our conceptual framework to process safety judgments. The criteria are already well supported in other industries[20,45-48]

and appear frequently in the investigative reports of the CSB.[2-4, 8] The persistence of process safety failures despite recognizing the relevance of competing criteria in process safety judgments indicates a gap between beliefs about approaching process safety judgments and behavior in making these judgments. The CUP gap provides educators with a tool to help surface the gap that exists between recognizing the relevance of process safety criteria (beliefs) and being able to proactively manage trade-offs between criteria in actual process safety judgments (behavior).

Research Question 2

The second research question sought to answer, "*How do chemical engineering faculty rankings of process safety judgment criteria change as a result of exposure to the group play-through of a portion of a process safety decision making game?"*

Figure 1 provides the median rankings for each of the competing criteria from the pre-CUP and post-CUP survey. Larger numbers represent higher prioritization of criteria.

Faculty ranked safety as the most important criteria in process safety judgments in both the pre-CUP and post-CUP surveys. This may reflect the significant emphasis that is placed on safety as part of the chemical engineering curriculum due to ABET requirements.[6] Effect sizes for ranking comparisons between safety and the other criteria were observed to be large (ranging from 0.70 to 0.905).[56] The numerical ranking results are also supported by faculty's open-ended responses to the survey questions, with two participants reaffirming in their post-CUP survey that safety should always be the first priority. The priority that the AIChE has placed on process safety through its CCPS echoes these results. CCPS makes the case for why process safety is so important through its tie to "corporate social responsibility, business flexibility, loss prevention, and sustainable growth" (pg. 3).[57] As part of this publication, CCPS argues the benefits that having a process safety culture will have on business operations overall and its benefit to the company's overall bottom line.

The relative rankings of criteria across the faculty rankings from pre-CUP to post-CUP remained fairly consistent

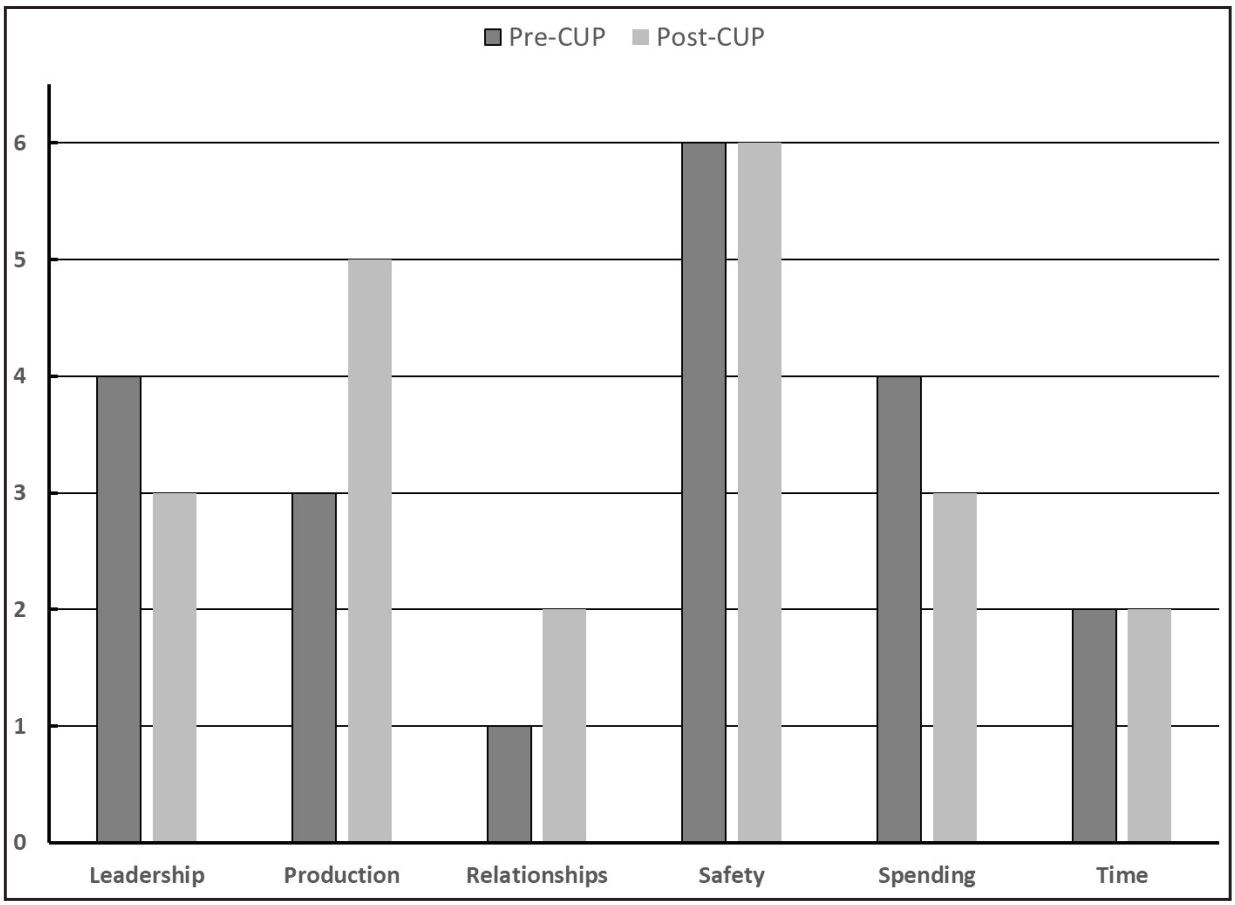

Figure 1. *Faculty median competing criteria rankings from pre-CUP and post-CUP game play. Most important criteria are represented by the largest number value.*

(Figure 1). Effect sizes for comparisons in the rankings of leadership, production, and spending were found to be large ($r > 0.5$)[56] while all other effect sizes were small ($r \sim 0.1$).[56] It is possible that this negligible difference in process safety judgment criteria ranking is attributed to the way in which CUP was implemented as part of this faculty workshop. Faculty played through only a small portion of the game (~20 judgments) as part of a large group exercise with group decision making rather than as individuals. As an educational intervention, CUP is typically implemented as a single person game over the course of 15 days with approximately 20 judgments made per day. Engaging in narrative based games, such as CUP, has been shown to generate enjoyment that could lead to the motivation necessary to change behaviors outside of the game environment.[58] Given that faculty were not provided the opportunity to fully engage in the game themselves, and only played in a group setting over a short period of time, it is possible that this may have limited change in their perception of the process safety criteria.

While faculty rankings did not shift notably, their perspective on the complexity of process safety judgments did noticeably change after CUP game play. In explaining the relative importance of the criteria, there was a shift towards acknowledging the complexity of real-life decisions and the human interpersonal relationships among five of seven participants after game play. Three of these participants explicitly discussed the human, personal, and interpersonal aspects of judgments, which have previously been reported as understudied in process safety.[20] Three participants described the difficulties of real-life decisions, such as in: "*Making judgments in real life settings is clearly different from making choices in the abstract*." These statements underscore the importance of context in judgments.

One explanation for this observed shift could be due to the game's authentic environment, which accentuates many elements of judgments that may otherwise be abstract when hypothetically considering these same judgments.[59] Relationships and environmental stressors are particularly poignant as the player interacts with the different characters, responds to their distinct and different demands, and hears the sounds of the coming storm. The player also responds to real-time performance feedback as their ratings for safety, relationships, and time/production shift with each decision made. The ability of games to facilitate learning through providing a context whereby the participant can meaningfully interact with their environment and obtain feedback provided on their judgments is well supported in the literature.[39-40] Faculty's increased recognition of context, particularly relationships and the stress of real-time pressure, in our pilot study add further support to this literature and underscore the potential value of CUP as an educational intervention that promotes faculty's ability to holistically discuss all the factors relevant to process safety.

SIGNIFICANCE TO THE CHE COMMUNITY

In this study, faculty were found to remain consistent in their rankings of process safety criteria before (pre-CUP) and after game play (post-CUP). This consistency could suggest that faculty may not consider the need to stress addressing competing criteria as part of their instruction because they themselves are not particularly susceptible to the influence of these criteria on their judgments. Faculty comments after game play show a heightened awareness of the impacts associated with competing criteria in process safety judgments, suggesting that CUP may serve as a useful tool to remind faculty of the complexity associated with approaching on-the-job judgments and subsequently impact the emphasis faculty place on competing criteria during their process safety instruction.

Faculty's greater experience level may be another explanation for their more consistent perceptions of the relative priority of criteria. Experience is a well-documented critical factor for developing expertise and supporting experts in making judgments.[30] In the domain of process safety, experience can allow engineers to more readily address competing criteria, but not all undergraduate students may have equal access to these experiences,[60] and certain groups (e.g., first-generation undergraduate students) partake in opportunities such as internships at lower rates.[61] Experience is by nature entwined with opportunity, and relying on extracurricular experiences is subsequently an inequitable avenue for expertise development. Embedding experiences in the classroom, such as through immersive game play as in CUP, can allow all students to develop their expertise and disproportionately benefit marginalized students who may have been historically or systematically excluded from gaining access to these experiences in co-curricular or extracurricular settings.

Process safety will always be important. The persistence of process safety incidents and the conclusion of the 2022 Sphera® report that the gap between industry's process safety goals and outcomes is increasing further support the urgency to reconsider our approach to teaching process safety.[2-4, 8, 62] The insights provided by this work support the need for widespread recognition of the complexity of process safety judgments and the value of CUP as a potential experiential learning tool for both students and faculty approaching these judgments.

CONCLUSIONS

Chemical engineering faculty serve an important role in the process safety education of chemical engineering students. Currently, the majority of process safety instruction

focuses upon safety through design rather than on judgments that are also integral in the avoidance of process safety incidents. New educational approaches are needed to support faculty in bringing the complexity of real-time process safety judgments to light in classroom settings. The digital process safety game, CUP, represents one innovative new tool for teaching process safety. This study sought to better understand the relevance that chemical engineering faculty members ascribe to process safety criteria that are involved in judgments and whether their ranking of these criteria changed as a result of exposure to a shortened group play-through of CUP with the aim of supporting its refinement for future implementations in the classroom. Overall, the chemical engineering faculty members believed all the identified process safety criteria to be relevant. Faculty rankings of the process safety criteria remained relatively stable, although they noted an increase in their ability to identify the complexity associated with these judgments after play through of CUP. We anticipate these findings being beneficial for allowing chemical engineering faculty members to reflect on how they frame process safety incidents in classroom discussions and also how they can address not only elements pertinent to safe design but also the competing criteria that may impact judgments made when working in chemical process safety environments.

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REFERENCES

1. Chemical Safety Board (CSB). Investigations. https://www.csb.gov/investigations/. Accessed June 29, 2023.
2. Chemical Safety Board (CSB). Kuraray Pasadena Release and Fire. https://www.csb.gov/kuraray-pasadena-release-and-fire/. Accessed December 21, 2022.
3. Chemical Safety Board (CSB). Caribbean Petroleum Refining Tank Explosion and Fire. https://www.csb.gov/caribbean-petroleum-refining-tank-explosion-and-fire/. Accessed October 21, 2015.
4. Chemical Safety Board (CSB). Philadelphia Energy Solutions (PES) Refinery Fire and Explosions. https://www.csb.gov/philadelphia-energy-solutions-pes-refinery-fire-and-explosions-/. Accessed October 11, 2022.
5. American Institute of Chemical Engineers (AIChE). History. https://www.aiche.org/ccps/history. Accessed February 27, 2023.
6. ABET Engineering Accreditation Commission (2021) *Criteria for Accrediting Engineering Programs*. ABET. Baltimore, MD.
7. Hendershot DC and Smades W (2007) Safety culture begins in the classroom. *Process Safety Progress*. 26(2): 83–84. doi: 10.1002/prs.10200.
8. Chemical Safety Board (CSB). Loy Lange Box Company Pressure Vessel Explosion. https://www.csb.gov/loy-lange-box-company-pressure-vessel-explosion-/ Accessed February 6th, 2023.
9. Stransky J (2023) Exploring Senior Chemical Engineering Students' Approach to Process Safety Decision Making [Rowan University]. https://rdw.rowan.edu/etd/3122/. Accessed Nov. 8, 2023.
10. Biddle E and Afanuh S (2015) Supporting Prevention through Design (PtD) Using Business Value Concepts. Cincinnati. https://www.cdc.gov/niosh/docs/wp-solutions/2015-198/pdfs/2015-198.pdf?id=10.26616/NIOSHPUB2015198. Accessed Nov. 8, 2023.
11. Willey RJ, Carter T, Price J, and Zhang B (2020) Instruction of hazard analysis of methods for chemical process safety at the university level. *Journal of Loss Prevention in the Process Industries*. 63: 1–9. doi: 10.1016/j.jlp.2019.103961.
12. Sheth JN and Stellner WH (1979) *Psychology of innovation resistance: The less developed concept (LDC) in diffusion research* (No. 622). Urbana-Champaign, IL, USA: College of Commerce and Business Administration, University of Illinois at Urbana-Champaign.
13. Bovill C, Cook-Sather A, Felten P, Millard L, and Moore-Cherry N (2016) Addressing potential challenges in co-creating learning and teaching: Overcoming resistance, navigating institutional norms and ensuring inclusivity in student–staff partnerships. *Higher Education*. 71: 195-208. doi:10.1007/s10734-015-9896-4.
14. Chandler N (2013) Braced for turbulence: Understanding and managing resistance to change in the higher education sector. *Management*. 3(5): 243-251. doi:10.5923/j.mm.20130305.01.
15. Khatri R, Henderson C, Cole R, Froyd JE, Friedrichsen D, and Stanford C (2016) Designing for sustained adoption: A model of developing educational innovations for successful propagation. *Physical Review Physics Education Research*. 12(1): 010112. doi: 10.1103/PhysRevPhysEducRes.12.010112.
16. Bodnar CA, Dringenberg E, Butler B, Burkey D, Anastasio D, and Cooper M (2020) Revealing the decision-making processes of chemical engineering students in process safety contexts. *Chemical Engineering Education*. 54(1): 1-9. https://journals.flvc.org/cee/article/view/107720. Accessed Nov. 8, 2023
17. Bazerman MH and Tenbrunsel AE (2012) *Blind Spots: Why We Fail to Do What's Right and What to Do About It*. Princeton University Press. Princeton, New Jersey.
18. Fernbach P and Sloman S (2017) *The Knowledge Illusion*. Penguin Random House Audio Publishing Group. New York, NY.
19. Fishbein M and Ajzen I (2011) *Predicting and Changing Behavior: The Reasoned Action Approach*. Taylor and Francis. New York, NY.
20. Baybutt P (1996) Human Factors in Process Safety and Risk Management: Needs for Models, Tools and Techniques. *Primatech*. https://www.primatech.com/images/docs/paper_human_factors_in_process_safety_and_risk_management_needs_for_models_tools_and_techniques.pdf. Accessed Nov. 8, 2023.
21. Kariuki SG (2007) Integrating human factors into chemical process quantitative risk analysis. *Reliability Engineering & System Safety*. 92(12): 1764-1773. doi:10.1016/j.ress.2007.01.002.
22. Baybutt P (2002) Layers of protection analysis for human factors (LOPA-HF). *Process Safety Progress*. 21(2): 119-129. doi:10.1002/prs.680210208.
23. Georgieva K, Neumann R, Fiegler A, and Dumke RR (2011) Validation of the Model for Prediction of the Human Performance. *In 2011 Joint Conference of the 21st International Workshop on Software Measurement and the 6th International Conference on Software Process and Product Measurement* (pp. 245-250). https://ieeexplore.ieee.org/document/6113067. Accessed Nov. 8, 2023.
24. Dougherty EM and Fragola JR (1988) *Human Reliability Analysis: Systems Engineering Approach with Nuclear Power Plant Applications*. Wiley-Interscience. New York, NY
25. Swain AD (1990) Human reliability analysis: Need, status, trends and limitations. *Reliability Engineering and System Safety*. 29(3): 301-313. doi:10.1016/0951-8320(90)90013-D.
26. French S, Bedford T, Pollard SJ, and Soane E (2011) Human reliability analysis: A critique and review for managers. *Safety Science*. 49(6): 753-763. doi:10.1016/j.ssci.2011.02.008.
27. Baddeley A (2003) Working memory: Looking back and looking forward. *Nature Reviews Neuroscience*. 4: 829-839. doi:10.1038/nrn1201.

28. Gevins A, Smith ME, McEvoy L, and Yu D (1997) High-resolution EEG mapping of cortical activation related to working memory: effects of task difficulty, type of processing, and practice. *Cerebral Cortex*. 7: 374-385. doi:10.1093/cercor/7.4.374.
29. Smith ME, McEvoy LK, and Gevins A (1999) Neurophysiological indices of strategy development and skill acquisition. *Cognitive Brain Research*. 7: 389-404. doi:10.1016/S0926-6410(98)00043-3.
30. Kahneman D, Slovic SP, Slovic P, and Tversky A (1982) *Judgment Under Uncertainty: Heuristics and Biases*. Cambridge University Press. Cambridge, England. doi: 10.1126/science.185.4157.1124
31. Lee C (2017) Awareness as a First Step Toward Overcoming Implicit Bias. In S. Redfield (Ed.), *Enhancing Justice: Reducing Bias* (pp. 289-302). ABA Book Publishing. doi:10.2139/ssrn.3011381.
32. Zeidan AJ, Khatri UG, Aysola J, Shofer FS, Mamtani M, Scott KR, Conlon LW, and Lopez B (2018) Implicit bias education and emergency medicine training: Step one? Awareness. *AEM Education and Training*. 3(1): 81-85. doi: 10.1002/aet2.10124.
33. Gill A, Thompson B, Teal C, Shada R, Fruge E, Villarreal G, Patton C, and Haidet P (2010) Best intentions: Using implicit associations test to promote reflection about personal bias. *The Journal of Teaching and Learning Resources*. doi: 10.15766/mep_2374-8265.7792.
34. Cairns P, Cox A, and Nordin AI (2014) Immersion in Digital Games: Review of Gaming Experience Research. Angelides, M.C. and Agius, H. *Handbook of Digital Games*. Wiley. Hoboken, New Jersey. doi: 10.1002/9781118796443.ch12.
35. Cheng K and Cairns PA (2005) Behaviour, realism, and immersion in games. *CHI EA '05: CHI '05 Extended Abstracts on Human Factors in Computing Systems*. https://dl.acm.org/doi/abs/10.1145/1056808.1056894.
36. Wilcox-Netepczuk D (2013) Immersion and realism in video games - The confused moniker of video game engrossment. *Proceedings of CGAMES'2013 USA*. doi: 10.1109/CGames.2013.6632613.
37. Qin H, Rau PP, and Salvendy G (2009) Measuring player immersion in the computer game narrative. *International Journal of Human–Computer Interaction*. 25(2): 107-133. doi: 10.1080/10447310802546732.
38. Ermi L and Mäyrä F (2005) Fundamental Components of the Gameplay Experience: Analysing Immersion. *Worlds in Play: Int. Perspectives on Digital Games Research*. https://www.researchgate.net/publication/221217389_Fundamental_Components_of_the_Gameplay_Experience_Analysing_Immersion. Accessed Nov. 8, 2023.
39. Dishon G (2021) The designability paradox: rethinking authenticity and situatedness in educational video games. *Educational Technology Research and Development*. 69: 497–513. doi: 10.1007/s11423-021-09992-5.
40. Squire K (2006) From content to context: Videogames as designed experience. *Educational Researcher.* 35(8): 19-29. https://www.jstor.org/stable/4124789. Accessed Nov. 8, 2023.
41. Crawford C (1997) *The Art of Computer Game Design*. Washington State University. https://www.digitpress.com/library/books/book_art_of_computer_game_design.pdf. Accessed Nov. 8, 2023.
42. Barab SA and Duffy T (2012) From practice fields to communities of practice. In D. Jonassen and S. Land (Eds.), *Theoretical Foundations of Learning Environments,* 2nd ed., pp. 25–55. Lawrence Erlbaum Associates. Mahwah, New Jersey.
43. Anastasio DD, Bassett L, Stransky J, Bodnar CA, Burkey DD, Cooper M (2020) Collaborative research: Designing an immersive virtual environment for chemical engineering process safety training. *2020 ASEE Annual Virtual Conference*. https://peer.asee.org/collaborative-research-designing-an-immersive-virtual-environment-for-chemical-engineering-process-safety-training. Accessed Nov. 8, 2023.
44. Stransky J, Bassett L, Anastasio D, Cooper M, Burkey DD, Bodnar CA (2020) Exploring student decision making trends in process safety dilemmas using the engineering process safety research instrument. *2020 ASEE Annual Virtual Conference*. https://peer.asee.org/exploring-student-decision-making-trends-in-process-safety-dilemmas-using-the-engineering-process-safety-research-instrument. Accessed Nov. 8, 2023.
45. Baybutt P (2017) The validity of engineering judgment and expert opinion in hazard and risk analysis: The influence of cognitive biases. *Process Safety Progress*. 37(2): 205–210. doi: 10.1002/prs.11906.
46. Dönmez K and Uslu S (2020) The effect of management practices on aircraft incidents. *Journal of Air Transport Management*. 84: 101784. doi: 10.1016/j.jairtraman.2020.101784.
47. Akinleye DD, McNutt LA, Lazariu V, and McLaughlin CC (2019) Correlation between hospital finances and quality and safety of patient care. *PLoS ONE*. 14(8): 1–19. doi: 10.1371/journal.pone.0219124.
48. Hendrickson C and Au T (2008) Quality Control and Safety During Construction. In C. Hendrickson (Ed.), *Project Management for Construction: Fundamental Concepts for Owners, Engineers, Architects, and Builders*. Prentice Hall. https://www.cmu.edu/cee/projects/PMbook/13_Quality_Control_and_Safety_During_Construction.html. (original work published 1989)
49. Encinsoa WE and Bernard DM (2005) Hospital finances and patient safety outcomes. *INQUIRY: The Journal of Health Care Organization, Provision, and Financing*. 42(1): 60-72. doi:10.5034/inquiryjrnl_42.1.60.
50. American Society for Engineering Education (ASEE) (2020). *Engineering and Engineering Technology by the Numbers 2019 Edition*. Washington, DC. https://ira.asee.org/wp-content/uploads/2021/02/Engineering-by-the-Numbers-FINAL-2021.pdf. Accessed Nov. 8, 2023.
51. Vigeant MA, Anastasio D, Barankin MDM, Bayles TM, Burkey DD, Ford LP, Gardner TQ, Koretsky M, Lepek D, and Liberatore MW (2022) Preliminary reflections and assessment of the 2022 Chemical Engineering Summer School. *2023 ASEE Annual Virtual Conference*. https://peer.asee.org/preliminary-reflections-and-assessment-of-the-2022-chemical-engineering-summer-school. Accessed Nov. 8, 2023.
52. Burkey DD, Anastasio DD, Bodnar C, and Cooper M (2020) Collaborative Research: Experiential Process Safety Training for Chemical Engineers. *STEM for All Video Showcase*. https://stemforall2020.videohall.com/presentations/1691. Accessed Nov. 8, 2023.
53. Serdar CC, Cihan M, Yücel D, and Serdar MA (2021) Sample size, power and effect size revisited: simplified and practical approaches in pre-clinical, clinical and laboratory studies. *Biochemia medica*. 31(1): 1-27. doi: 10.11613/BM.2021.010502
54. American Statistical Association (2016) American Statistical Association Releases Statement on Statistical Significance and P-Values: Provides Principles to Improve the Conduct and Interpretation of Science. https://www.amstat.org/asa/files/pdfs/p-valuestatement.pdf. Accessed July 8th, 2023.
55. Fritz CO, Morris PE, and Richler JJ (2012) Effect size estimates: Current use, calculations, and interpretation. Journal of Experimental Psychology: General. 141(1): 2–18. doi:10.1037/a0024338.
56. Ellis PD (2010) The Essential Guide to Effect Sizes Statistical Power, Meta-Analysis, and the Interpretation of Research Results. Cambridge University Press, 41.
57. The Center for Chemical Process Safety (CCPS) (2018) *The Business Case for Process Safety.* 4th edition. AIChE. New York, New York. https://www.aiche.org/ccps/about/business-case-process-safety. Accessed Nov. 8, 2023.
58. Zhou C, Occa A, Kim S, and Morgan M (2019) A Meta-analysis of Narrative Game-based Interventions for Promoting Healthy Behaviors. *Journal of Health Communication*. 25(1): 54-65. doi:10.1080/10810730.2019.1701586.
59. Stransky J, Bodnar C, Cooper M, Anastasio DD, and Burkey DD (2020). Authentic process safety decisions in an engineering ethics context: expression of student moral development within surveys and immersive environments. *Australasian Journal of Engineering Education*. doi:10.1080/22054952.2020.1809881.
60. Hora M, Chen Z, Parrott E, and Her P (2020) Problematizing college internships: Exploring issues with access, program design and developmental outcomes. *International Journal of Work-Integrated Learning*. 21(3): 235–252.
61. Hoekstra CE (2021) Examining Demographic and Environmental Factors that Predict Undergraduate Student Participation in Internships [State University of New York at Buffalo]. In ProQuest Dissertations and Theses. https://www.proquest.com/openview/a342647fac24527365efd4da68c136fa/1?pq-origsite=gscholar&cbl=18750&diss=y Accessed Nov. 8, 2023.
62. Sphera Insights (2022, Oct 20). Safety Report 2022. Sphera. https://sphera.com/report/safety-report-2022/. Accessed Nov. 8, 2023.❑