Education for Chemical Engineers 35 (2021) 22–28

Contents lists available at ScienceDirect

Education for Chemical Engineers

journal homepage: www.elsevier.com/locate/ece

# A retrospective analysis on the impacts of an immersive digital environment on chemical engineering students' moral reasoning

Jeffrey Stransky[a], Landon Bassett[b], Cheryl Bodnar[a,*], Daniel Anastasio[c], Daniel Burkey[b], Matthew Cooper[d]

[a] Department of Experimental Engineering Education, Rowan University, Glassboro, NJ, United States
[b] Department of Chemical and Biomolecular Engineering, University of Connecticut, Storrs, CT, United States
[c] Department of Chemical Engineering, Rose-Hulman Institute of Technology, Terre Haute, IN, United States
[d] Department of Chemical and Biomolecular Engineering, North Carolina State University, Raleigh, NC, United States

ARTICLE INFO

*Article history:*
Received 28 August 2020
Received in revised form 4 December 2020
Accepted 22 December 2020
Available online 31 December 2020

*Keywords:*
Games
Ethics
Experiential learning
Senior undergraduate
Student assessment

ABSTRACT

Process safety decision making in chemical engineering practice has a strong ethical and moral component. While effective process safety decision making can be taught, it is not solely a technical topic, and includes complex behavioral elements that classroom-based instruction finds difficult to capture. To capture the complexity of this decision making, we have developed a digital immersive environment, *Contents Under Pressure* (CUP), that includes both technical and behavioral elements. This immersion allows participants to explore realistic process safety decision points in a safe environment. To determine the effect of CUP on moral reasoning, a retrospective study of two cohorts was conducted. The first cohort (n = 109) received traditional process safety instruction, and the second cohort (n = 181) had CUP included as part of their instruction. Pre- and post-assessment of participant process safety reasoning was achieved via the Engineering Process Safety Reasoning Instrument (EPSRI), also developed by the authors. Analysis of the data suggests that exposure to CUP has a distinct and statistically significant impact on process safety reasoning as compared to the comparison cohort.


## 1. Introduction

### 1.1. Process safety instruction

Process Safety is an integral part of a chemical engineer's work, and its importance is reflected in multiple parts of the (AIChE) Code of Ethics (AICHE, 2020) but most clearly in the first point: Chemical engineers should "...hold paramount the safety, health and welfare of the public and protect the environment in performance of their professional duties." It is therefore critical that chemical engineering students have a solid and realistic understanding of process safety during their education such that they are prepared to make sound decisions in practice post-graduation.

In the early 2000′s, following a number of high-profile chemical accidents, AIChE and ABET (the United States engineering accrediting body) mandated that chemical process safety and identification of process hazards be included in chemical engineering curricula. The result has been an intense interest in how this crucially important topic is taught in the university setting. Both Mkpat et al. (2018) and Dee et al. (2015) have excellent and recent reviews on the subject. The literature reveals that the approaches to teaching process safety are diverse, and that no single curriculum or approach has taken hold as a 'standard' in comparison to what has occurred for other traditional topics in the chemical engineering curriculum. This strategy has resulted in varied educational approaches, which can generally be collected into two main categories - integration of safety instruction into existing courses in the curriculum versus standalone treatments of the subject. There have been numerous examinations of the relative effectiveness of these two approaches in the literature (Pintar, 1999; Willey et al., 2011), which perhaps captures the challenge of teaching process safety - is it a standalone topic that can be taught similarly to process control, kinetics, or thermodynamics, or is it a fundamental underpinning of engineering subjects that should therefore be threaded throughout the curriculum? The chemical engineering community has tried to provide resources for both approaches - for example, Crowl and Louvar's widely renowned text on the subject (Crowl and Louvar, 2001), the Safety and Chemical Engineering Education Committee (SACHE) development of educational resources that can be included in various chemical engineering core courses (Spicer

* Corresponding author.
*E-mail address:* bodnar@rowan.edu (C. Bodnar).

https://doi.org/10.1016/j.ece.2020.12.003

et al., 2013), and the incorporation of process safety material in the AIChE Concept Warehouse (Vaughen, 2019).

Outside the United States, the Bologna Process has standardized European university engineering programs' process safety curricula, revealing process safety's global value (Cortés et al., 2012; Schonbucher et al., 2013). Universities in both Spain and Germany have explored methods to improve their process safety education. Cortés et al. (2012) utilized the Delphi method with a panel of 60 experts to analyze the engineering curricula in Spanish universities, ultimately reaching a consensus that occupational risk prevention should be included in some capacity. As in the United States, Krause (2016) looked at two curricular design approaches: one where process safety is a specialized course topic and one where process safety is integrated throughout a chemical engineering degree program. They analyzed the pros and cons towards both degrees, concluding that a specialized Master's program working closely with industrial partners could be a solution for German education.

Perhaps two of the most interesting ideas to arise out of the Process Safety Education literature are its connections to constituencies outside the engineering education community: industrial practitioners and behavioral science. Given the strong industrial nature of process safety (and it being distinctly different from *laboratory* safety, which is often a focus at the undergraduate level), there have been numerous investigations of increased collaboration or input from industrial partners in teaching process safety (Pitt, 2012; Dixon and Kohlbrand, 2015; Hassall et al., 2020; Willey et al., 2020). As industrial partners are practitioners, their expertise in realistic process safety scenarios is highly valuable, especially given that many academic faculties have not held industrial positions and lack that particular first-hand experience.

The behavioral science connection is interesting because it recognizes the fact that process safety is at least as much about human psychology, risk assessment, and behavior as it is about technical engineering knowledge. In recent years, the psychological element of process safety has been explored, with investigation of "human factors" (Rodriguez et al., 2017), the role of memory (Throness, 2014), and the role of complacency (Hyten and Ludwig, 2017).

### 1.2. Behavioral ethics and immersive learning environments

While safety and ethics instruction are essential for chemical engineering students, elements of human psychology can cause practicing chemical engineers to overlook some safety and ethics decisions that appear daily in the workplace. Whether due to pressures related to time or monetary constraints, a deference to authority, or a lapse in ethical judgment, individuals often commit actions with negative ethical and safety consequences (Milgram, 1963; Burger, 2009). These actions can have severe consequences in the chemical industry, including loss of human life. The apparent contradiction between increased safety and ethics training within university settings and the continued unethical action taken in industry highlights the difference between *ethics* and *behavioral ethics*. While ethics seeks to provide guidance for the appropriate or moral way to act, behavioral ethics seeks to study how individuals actually behave when placed in a scenario that requires an ethical decision (Bazerman and Tenbrunsel, 2011).

Behavioral ethics can explain many of the disconnects between education and practice. For instance, during a class that discusses safety or ethics, many students are aware they are being presented with an ethical dilemma. The students often make predictive answers that sound the "best", most correct, or most ethical, but do not actually reflect how they would react within the presented scenario (Osberg and Shrauger, 1986). Previous studies by the authors using the Engineering Process Safety Research Instrument (EPSRI) showed that the majority of students scored very highly in their ethical reasoning, but this was likely because they were still operating in the predictive phase and selected the decisions that sounded the most ethical (Butler et al., 2019; Bodnar et al., 2020; Stransky et al., 2020a). In engineering practice, ethical issues are rarely as clearly presented as they are in case studies. Thus, this predictive strategy, which is predicated on the ability of an individual to identify when decisions have ethical components, can fall short. One cannot engage with the appropriate safety and ethics thought processes when one cannot identify that a decision has an ethical element (Bazerman and Tenbrunsel, 2011).

Therefore, to avoid the pitfalls associated with natural human tendencies related to behavioral ethics, it may seem like the best safety education would be to allow students to practice making decisions in real-world environments as soon as possible. This strategy, known as preauthentication, relies on placing students in an immersive, real-world environment and allows them to make decisions and actions in a realistic context, including external influences one may not experience in a non-immersive setting (Nicaise et al., 2000; Radinsky et al., 2001). Studies suggest preauthentication is effective for general engineering and engineering ethics education (Shepherd, 1986; Koretsky et al., 2008; Manenti, 2012; Dholakiya et al., 2019). Preauthentication environments have also been demonstrated to provide more effective instruction than a non-interactive environment due to the preauthentication environment's propensity to promote active learning and engagement (Bransford et al., 1999; Pascarella and Terenzini, 2005).

However, given the nature of chemical engineering and common industrial applications thereof, it may be difficult and likely unsafe for a chemical engineering student to be placed in a real-life scenario where they can practice making safe and ethical decisions. Therefore, to teach safety and ethics using preauthentication strategies, simulations or serious games can be used. To this end, the authors have developed a digital immersive environment called *Contents Under Pressure* (CUP) (Anastasio et al., 2020; Stransky et al., 2020a). In CUP, the student is placed in a supervisory role at a chemical engineering plant and must make a series of binary decisions, some mundane and others critical. These decisions involve balancing plant safety, plant productivity, perception by coworkers and the general public, and time. By teaching decision-making using an environment that more closely mimics an actual industrial environment, students can learn to move out of the predictive mindset and behave in a way that more accurately reflects their actual level of moral development, potentially leading to further reflection and instruction.

Studies have shown that digitally immersive contexts can improve students' understanding and decision-making ability in other disciplines. Pasinand and Giroux (2011) conducted a study on operations management and Reiners and Wood (2013) led another on supply chain management. Both industry-centric contexts showed evidence of student improvement in decision-making when handling complex scenarios. However, CUP is unique in that it focuses specifically on the ethics of process safety. While the context of Pasinand and Giroux (2011); Reiners and Wood (2013) showed improvements in operations based on optimal or correct decision-making, process safety is more ill-structured. Therefore, to observe improvement, a lens of moral reasoning is used.

### 1.3. Moral reasoning

Kohlberg's moral development theory expresses the moral thought process as three distinct levels (Kolhberg and Hersh, 1977). The earliest point of moral development is pre-conventional reasoning. A person who operates at the pre-conventional level makes decisions based on their own personal interest and how it might affect them (Kolhberg and Hersh, 1977). They would hope for outcomes that directly benefit them and minimize their own personal

**Table 1**
Comparison of Rest's Schemas with Kohlberg's Stages.

| | Pre-conventional | Conventional | Post-Conventional |
|---|---|---|---|
| Consolidated | Type 1 | Type 4 | Type 6 |
| Transitional | Type 2 | Type 3 | Type 5 |

risk; for instance, a person at the pre-conventional level might do a favor because they would expect a favor in return. The next level is conventional reasoning. A person who is at the conventional level makes decisions concerning others in their immediate social circle; this could include family, friends, co-workers, or neighbors (Kolhberg and Hersh, 1977). A person using conventional-level reasoning might do a favor for someone else because that person is a close friend and they want to maintain that relationship. The final level of moral reasoning is post-conventional. Individuals make decisions at the post-conventional level when they consider outcomes that affect a wider population than just their friends and families. Post-conventional reasoning is concerned with the environment, society at large, or the greater good (Kolhberg and Hersh, 1977). A person applying post-conventional reasoning does someone a favor because they believe certain moral rights are universal and that following their principles will lead to a better outcome for society overall.

While Kohlberg viewed these levels as rigid, where one is either at the conventional level or the post-conventional level, Rest saw them as more flexible. This means that a person's reasoning could instead exist between levels as they begin to transition from one stage to the next (Rest et al., 2000). A person could move between two stages and even apply lower levels of reasoning within their decisions depending on context. Stransky et al. (2020a) illustrates this relationship with three inscribed circles. The innermost circle is denoted as pre-conventional, and each subsequent ring extends out from there, with the outermost ring as post-conventional. Even though a person could think at the post-conventional level, they do not necessarily make all their decisions at that level. They are free to reason at all levels, up to their highest. So, much like how the inscribed circles grow outward from pre-conventional thinking, a person is never fully divorced from those lower levels of thought. Instead of three levels, Rest developed six schemas, shown in Table 1 (Rest et al., 1999a). These new schemas account for an individual's moral consistency.

Three of the schemas, Type 1, Type 4, and Type 6, are similar to Kohlberg's stages of moral reasoning, where an individual is consolidated in a single level of moral reasoning. The other three schemas take into account the possibility that someone is transitioning between schemas, called morally transitional. For example, if a person is Type 4, then they are consolidated in conventional reasoning, but if they are Type 3, they are predominantly conventional in their reasoning, yet they are transitioning towards either pre-conventional or post-conventional. While a person is in a transitional schema, Thoma and Rest (1999) believe that it becomes harder to define their moral consistency using Kohlberg's stages. A transitional person may come into conflict with the different stages and ultimately choose another method to justify their decisions, such as looking to social norms. The existence of transitional schemas in between the stages shows that a person's moral journey is not as clear cut as Kohlberg initially thought.

### 1.4. Research questions

This paper seeks to address the following two research questions: (1) How does participation in a digital immersive process safety environment influence the moral reasoning of senior chemical engineering students? and (2) What differences exist in the moral schema of senior chemical engineering students when exposed to a digital immersive process safety environment in comparison to standard process safety instruction?

## 2. Methods

### 2.1. Study design

This study sought to perform a retrospective comparison of process safety decision making among three different ABET-accredited chemical engineering programs. Senior chemical engineering students that were enrolled in either a senior design, process safety, or professional practice class participated in the study. Across the three institutions there were a total of 109 participants in Year 1 and 181 participants in Year 2. During Year 1 of the study, students received standard process safety instruction while during Year 2 of the study students played through *Contents Under Pressure* (CUP) in addition to their standard process safety instruction. Instructors utilizing CUP in their course introduced the intervention and the importance of training in authentic process safety decision making prior to granting access to CUP. Although implemented alongside course content, interaction with the immersive environment was not restricted to class time, was independent from lecture content, and could be accessed on a personal computer through a website link. In this study, process safety decision making was measured through use of the Engineering Process Safety Research Instrument (EPSRI) which was administered at the start (Pre-) and near the end (Post-) of each course offering; the EPSRI is discussed in the following section. Proper human subjects' approval was obtained prior to proceeding with data collection and analysis.

### 2.2. EPSRI

One approach to assessing a person's moral development is to present them with a written prompt describing one or more ethical dilemmas which have realistic incentives and disincentives to weigh before a decision can be made. Once the respondent has made their decision, they can then self-report which of a number of listed factors played the largest role in their decision. Based on one's responses, an estimation can be made of the level of moral reasoning exhibited by the person while making their decision. The seminal exemplar of this approach is the updated Defining Issues Test (DIT-2) based on a Neo-Kohlbergian ethical framework (Rest et al., 1999a;b). Using the DIT-2 as a model, the authors developed the EPSRI as an approach to measure the process safety decision making behaviors (in contrast to the focus of the DIT-2 on general ethics alone) of senior undergraduate chemical engineering students. Development of the EPSRI has been a multi-year effort spanning initial instrument development, content validation (Butler et al., 2018), qualitative and quantitative analysis of student responses (Butler et al., 2019; Bodnar et al., 2020, Stransky et al., 2020b), and ongoing reliability testing at multiple institutions.

The version of the EPSRI tested in this paper contains six dilemmas, each of which provide the respondent with three decision options and 10–12 considerations on which they provide feedback through ratings and rankings regarding the impact of each consideration on their proposed decision. After they have rated the 10–12 considerations, the respondent is then asked to rank their top four considerations. This feedback is used to calculate the respondent's N2 score, CDIT score, and predominant reasoning. The N2 score, named for being the second "new" index for assessing moral reasoning, describes the extent the respondent reasons in a post-conventional manner in the absence of reasoning in a pre-conventional manner (Rest et al., 1997b). A higher N2 score would be evidence of greater post-conventional reasoning. In practice, the score is calculated by considering the rating and ranking of pre-conventional and post-conventional considerations. The CDIT score, named for being the DIT consolidation score, describes the respondent's moral consistency as either transitional or consolidated. This score is calculated by considering how the respondent rated considerations from each of the three levels of moral reasoning. Predominant reasoning describes the level of moral reasoning in alignment with the respondent's behavior and is calculated with respect to the N2 and CDIT scores. Note, none of these scores take into consideration the respondent's proposed decision to any of the dilemmas. Previous publications by the authors provide sample calculations for these scores (Butler et al., 2019) and an example of a dilemma contained in the EPSRI (Stransky et al., 2020b).

### 2.3. Contents under pressure

The authors have developed a digital immersive environment called *Contents Under Pressure* (CUP) to teach safety and ethics with preauthentication. Users can progress through CUP's story arc through a 10–15 minute session on each of 15 days. Within each session, CUP places the user in the role of a newly hired senior engineer at a chemical engineering plant, where they manage employees and respond to their supervisor and safety advisor by making binary decisions ranging from the mundane (e.g. whether to join a co-worker for lunch) to the critically important (e.g. whether to allow an untrained worker to complete a difficult task). The immersion challenges the user's judgement ability as a hurricane makes landfall over their plant. In CUP, meters are provided which gauge the user's performance in four key areas of their job: (1) time management, (2) personal reputation based on work and family relationships, (3) productivity of the unit they manage, and (4) level of process safety. Each decision made by the user in CUP impacts these meters; for instance, taking a long lunch with a co-worker may negatively impact the time management meter, but positively impact the reputation meter. When making a decision, the meters will flash as the user hovers their mouse over a potential response warning them which metric will be impacted, but not indicating whether that impact will be positive or negative. An imbalance in prioritizing these four meters can lead to a "failure" which deducts points from the user's final score but does not immediately end the experience for the player.

By placing the user in a preauthentication environment, the user becomes immersed in not only the narrative, but also their desire to perform well on the various metrics associated with the environment. This preauthentication strategy intends to blur the user's perception of decisions as mundane versus important, as well as whether their decisions have an ethical component. This latter result is important to capture the effect of "ethical fading," described by behavioral ethicists Bazerman and Tenbrunsel as the tendency of humans to fail to recognize the ethical considerations of their decisions when other incentives and disincentives are at stake (Bazerman and Tenbrunsel, 2011). A previous comparison of student moral reasoning using both the EPSRI and CUP has shown that students tend to apply more conventional reasoning when faced with the preauthentication environment of CUP compared to more post-conventional reasoning with the EPSRI (Stransky et al., 2020a).

It is possible that CUP may meet the criteria of a serious game, as defined by Mildner and Mueller (2016, p. 59), by providing users with engagement, amusement, storytelling, rules, and opportunities to learn. Some serious game studies have been insistent on the impact of sample demographics and gamer experience (Orvis et al., 2010). However, our previous work has identified that CUP does not elicit behavioral differences based on gender or self-identification as a gamer (Cooper et al., 2020). More information on the development of CUP can be found elsewhere (Burkey et al., 2020; Anastasio et al., 2020).

### 2.4. Data analysis

Students' N2-scores, CDIT scores, and students' predominant moral reasoning (schema type) were determined based on student rating and rankings on the EPSRI. N2-scores of the first and second year cohorts were compared using ANCOVA for statistical significance and $\eta^2$ for effect size. A covariance analysis is required to account for covariate errors which are evident in the baseline (or Pre-) N2 scores between the two years under investigation (Philippas, 2014).

Changes in predominant moral reasoning (schema type) were compared between the Pre- and Post- semester results for both of the two cohorts using a Stuart-Maxwell test. Schema consistency between consolidated and transitional moral reasoning within a specific schema is determined through the CDIT score, where a CDIT score of less than 15.705 is considered transitional and a CDIT score greater than 15.705 is considered consolidated (Rest et al., 1999a). Schema consistency was compared using a McNemar analysis. All statistical comparisons were performed using IBM SPSS 26 to determine the significance of the comparisons.

## 3. Results and discussion

The purpose of this study is to measure the impacts of digital immersion within *Contents Under Pressure* (CUP) as part of process safety instruction on students' moral reasoning. Specifically, the first research question is, "How does participation in an immersive digital process safety environment influence the moral reasoning of senior chemical engineering students?" For this research question, moral reasoning is measured using the students' N2 scores which are compared using ANCOVA. The Pre-, unadjusted Post-, and adjusted Post- N2 scores and the result of ANCOVA are shown in Table 2. Each of the N2 scores are indicative of post-conventional reasoning. The Pre- N2 results differ from covariate errors perhaps caused by different ethical experiences prior to engaging with the EPSRI. The unadjusted Post- results show both cohorts increased in N2 scores over the course of the semester. The adjusted Post- results show that the intervention cohort had a significantly greater N2 score than the comparison cohort, $p = 0.015$, with a small effect size, $\eta^2 = 0.020$. These results suggest the intervention cohort more heavily utilized post-conventional moral reasoning than the comparison cohort while responding to the EPSRI at the end of the semester. To help illustrate what change is taking place in the intervention cohort, Table 3 shows how the average rating of two considerations change in regards to an EPSRI dilemma about whether or not to falsify a spill report to avoid a fine. In this dilemma, the respondent is receiving pressure from their boss to ignore a spill rather than report it and is informed by a co-worker that this approach was also taken with their predecessor who left the company shortly after the last spill took place. Looking between Pre- and Post-, the averages show an increase in a pre-conventional rating and a decrease in a post-conventional rating. This implies that the respondent may now consider that personal reputation, associated with the pre-conventional rating, has greater importance to them after playing through the immersion then it did at the start of process safety instruction. Meanwhile, the decrease in post-conventional ranking suggests that the respondent might have a more nuanced understanding of the safety implications associated with spill reporting. The results of Table 3 have no statistical power and are only included to illustrate how the intervention cohort changed what types of considerations they found as important.

Rest performed experiments using the Defining Issues Test (DIT) and the DIT2 to show how increasing levels of education, such as high school, college and graduate or professional schools, are positively associated with higher levels of p-scores and N2 scores

**Table 2**
Changes in N2 scores for each cohort and ANCOVA comparison.

| | Pre- N2 Mean | Unadjusted Post- N2 Mean | Adjusted Post- N2 Mean | P-value | Effect size, $\eta^2$ |
|---|---|---|---|---|---|
| Comparison Cohort | 50.2 | 51.8 | 56.1 | 0.015 | 0.020 *small effect* |
| *Contents Under Pressure* Intervention Cohort | 62.1 | 63.0 | 60.4 | | |

**Table 3**
Changes in rating of sample considerations from the EPSRI, n = 181.

| Level of moral reasoning | Description | Pre-test | | Post-test | |
|---|---|---|---|---|---|
| | | Mean Rating | Standard Deviation | Mean Rating | Standard Deviation |
| Pre-conventional | Can you avoid being placed in the same position as the previous engineer who was put under pressure while preparing the report? | 3.03 | 1.27 | 3.33 | 1.05 |
| Post-conventional | What are the long term environmental impacts if the spills continue unreported? | 4.59 | 0.75 | 4.49 | 0.81 |

(Rest et al., 1997a, b). It was found that college students typically operate in a conventional level of moral reasoning, and moral philosophers, the highest scoring population, operate at a post-conventional level. From these results many other researchers have adopted the belief that ethics interventions should seek to increase students' moral reasoning towards post-conventionalism. This approach has been found in other studies including those performed in pharmaceutical, physical therapy, recreational management, and journalism ethics course settings (Hanna et al., 2017; Swisher et al., 2012; Craig and Oja, 2013; Auger and Gee, 2016).

The goal of this work, however, is not necessarily to direct an individual towards a specific level of moral reasoning but rather to provide an opportunity to gain exposure to making these types of judgements within an authentic environment as provided in the CUP setting. In this manner, it may be possible to provide students with the opportunity to determine if there are any differences between the way they respond to prompts in a testing environment, such as the EPSRI, and in a more authentic context, as provided through CUP. Prior research on this project has shown that students may score as post-conventional in testing environments, also shown in the EPSRI results in Table 2, but that this might not reflect the same moral reasoning they apply in the authentic environment itself. These results suggested students' valuation of post-conventional considerations was reduced because the immersive context exposed complex motivations which were not obvious while predicting their behavior within the EPSRI context (Stransky et al., 2020a). Studies from Rest et al. are suggestive that college level students may realistically be confined to a conventional level of moral reasoning while performing in the field inherent to their depth of experience (Rest et al., 1997a, 1999b). By illustrating differences in moral reasoning between these two contexts during safety or ethics training, it may be possible to reduce unethical actions in industry associated with errors in predicting behavior (Osberg and Shrauger, 1986).

The results from this current study may lead to a question as to whether digital immersion had any lasting, measurable impact on students' moral reasoning? This factor is addressed through the second research question, which asks, "What differences exist in the moral schema of senior chemical engineering students when exposed to an immersive digital process safety environment in comparison to standard process safety instruction?"

This second research question is initially addressed by investigating the changes in moral schema type as shown in Fig. 1. Fig. 1 shows a trend where the comparison cohort generally increased in their schema type. We see that the majority of the 11 % change in Schema 5 is accounted for by the 9.2 % increase in students who were found in Moral Schema 6 over the semester, in general representing further consolidation. In comparison, the intervention cohort shows a *decrease* in post-conventional consolidated thinking, with an 8.3 % decrease in Schema 6 largely redistributed downward into Schema 5 (5.5 %, transitional post-conventional) and even Schema 3 (4.4 %, transitional conventional). These results demonstrate that particularly over the fifth and sixth schema types, the cohorts have stark opposing trends. These trends in moral schema changes were statistically analyzed using the Stuart-Maxwell test. The comparison cohort was found to have no statistically significant difference in the proportions between Pre- and Post-, p = 0.752, whereas the intervention cohort was found to have a statistically significant difference in the proportions between Pre- and Post-, p = 0.013.

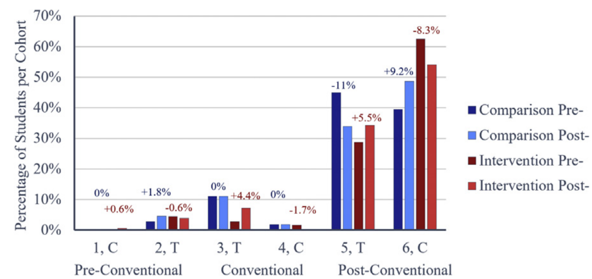


**Fig. 1.** Changes in moral schema type Pre- and Post- course for each cohort.

These two statistical tests are supplemented with a McNemar test comparing how students changed in their moral consistency by comparing changes in moral consolidation and moral transition. The results of these changes are visible in Fig. 1 where each schema type is associated with a "C" (for consolidation) or a "T" (for transition). Table 4 shows the numbers and percentages of students for each cohort that were found to be either consolidated or transitional in their moral reasoning. The comparison cohort's McNemar test found there was no statistically significant difference in students' moral consistency between Pre- and Post-, p = 0.123. The intervention cohort's McNemar test found there was a statistically significant difference in moral consistency between Pre- and Post-, p = 0.010. Despite each cohort having approximately a 10 % change in moral consistency over the course of the semester, the McNemar test demonstrates that the intervention cohort had more student changes in moral consistency than the comparison cohort.

As described earlier, moral transition may be used to describe how non-discriminant students may be towards one or more levels of moral reasoning, and moral consolidation may be used to describe how focused students are within a single level of moral reasoning. These results imply that the intervention cohort that interacted with CUP became more apt at using multiple levels of moral reasoning. Literature shows that students in a transitional moral schema are better prepared to make advances in their

**Table 4**
Number and percentage of students by moral consistency for each cohort.

| | Pre- Course | | | | Post- Course | | | |
|---|---|---|---|---|---|---|---|---|
| | Consolidated | | Transitional | | Consolidated | | Transitional | |
| | n | % | n | % | n | % | n | % |
| Comparison Cohort | 45 | 41.2 % | 64 | 58.7 % | 55 | 50.5 | 54 | 49.5 % |
| *Contents Under Pressure* Intervention Cohort | 116 | 64.1 % | 65 | 35.9 % | 99 | 54.7 % | 82 | 45.3 % |

moral reasoning (Derryberry and Thoma, 2005; Thoma and Rest, 1999). Mayhew et al. (2012) confirms this in their retrospective study of first year college students using the DIT2 where transitional students at the beginning of the study made significantly greater advancements in their moral reasoning than those who were morally consolidated. It is possible the shift from schema six to five in the intervention cohort is evidence of students integrating their immersive experience from CUP into their moral reasoning structure as a result of the digital immersion. As discussed previously, senior university students would not be expected to regularly operate in schema six, indicating that CUP allows a more accurate representation of student decision making and that CUP may enable students to become more prepared to adjust their moral reasoning.

It is important to acknowledge the impact of time on changes in moral reasoning. When Rest et al. found a relationship between level of moral reasoning and the degree of education, these degrees were spaced several years apart perhaps due to the time required to accumulate experience (Rest et al.,1997a, 1999b). This may be connected to the duration of immersion not being enough to create a lasting impact. CUP is shown to be altering students' predominant reasoning and moral consistency, but its current duration may be limited in its ability to create lasting change in students' moral reasoning. The change towards transitional consistency suggests that students are becoming more prepared to alter and adjust their moral reasoning, but this change is not observed with respect to overall level of moral reasoning where both cohorts were found to increase in N2 scores over the course of the semester. It is possible that by increasing the immersion duration, students would accumulate more experience in making ethical judgments and, in doing so, may have noticeable impacts to their levels of post-conventional reasoning.

### *3.1. Limitations*

Allowing respondents to complete multiple attempts of ethical testing instruments has been associated with increased levels of post-conventional moral reasoning (Mayhew et al., 2015). For this reason, it is possible scores from the EPSRI may not fully reflect students' moral reasoning as they may have increased solely from interacting with the instrument a second time. This study is also limited in that it only encompasses the results from three institutions. Results may change based on student population and institutional context.

## 4. Conclusions

A retrospective cohort model was employed to examine the process safety reasoning of two distinct groups of students, one that received traditional process safety instruction (comparison), and one that had access to the digital immersive environment *Contents Under Pressure* (intervention). While both the cohorts saw changes in their reasoning abilities as measured by the EPSRI, the comparison group was consolidated in their post-conventional thinking. Additionally, their moral consistency, as measured by McNemar's test, did not show statistically significant changes between the pre- and post-instruction EPSRI assessments. In contrast, students who were given access to CUP showed the opposite trend of the comparison group, moving from consolidated post-conventional reasoning towards transitional post-conventional reasoning. These changes were statistically significant, as was McNemar's test for moral consistency.

Taken together, these results support the idea that CUP, with its immersive and complex nature, is requiring students to think differently about their process safety decisions. Because these decision points are presented in a more authentic context, students are less aware that they are being faced with an ethical or safety decision, much as in "real life", and therefore their decisions reflect that ambiguity. The movement of students from the consolidated schema to the transitional schema suggests the recognition of the complexity of these decisions and is more in line with other measurements of college-aged students' ethical reasoning, which is often predominately conventional. Further training within a preauthentication environment, such as the one provided by CUP, may help students practice engaging in real-time, rather than predictive, ethical decision making, potentially better equipping them to make these judgments in the real world post-graduation.

## Declaration of Competing Interest

The Authors (Cheryl Bodnar, Matthew Cooper, Daniel Anastasio, and Daniel Burkey), Rowan University, North Carolina State University, Rose-Hulman Institute of Technology, University of Connecticut, and Filament Games are joint owners of the developed process safety game Contents Under Pressure and may stand to gain financially from the digital game that is described within this publication.

## Acknowledgements

The work was supported by the National Science Foundation (NSF) Improving Undergraduate STEM Education [IUSE DUE#1711376, 1711644, 1711672, and, 1711866] for which the authors are very grateful.

The authors would also like to thank Filament Games for their development of *Contents Under Pressure*.

## References

American Institute for Chemical Engineering, 2020. AIChE Code of Ethics (Accessed 25 August 2020) https://www.aiche.org/about/code-ethics/.
Anastasio, D.D., Bassett, L., Stransky, J., Bodnar, C.A., Burkey, D.D., Cooper, M., 2020. Collaborative Research: Designing an Immersive Virtual Environment for Chemical Engineering Process Safety Training Paper Presented at 2020 ASEE Virtual Annual Conference Content Access , Virtual Online https://peer.asee.org/34301.
Auger, G., Gee, C., 2016. Developing moral maturity: an evaluation of the media ethics course using the DIT-2. J. Mass Commun. Educ. 71 (2), 146–162, http://dx.doi.org/10.1177/1077695815584460.
Bazerman, M., Tenbrunsel, A., 2011. Blind Spots: Why We Fail to Do What's Right and What to Do About It. Princeton University Press.
Bodnar, C., Dringenberg, E., Butler, B., Burkey, D., Anastasio, D., Cooper, M., 2020. "Revealing the decision-making processes of chemical engineering students in process safety contexts,". Chem. Eng. Education 54 (1), 22–30.
Bransford, J., Brown, A., Cocking, R., 1999. How People Learn: Brain, Mind, Experience, and School. National Academies Press, Washington, DC.
Burger, J., 2009. Replicating milgram: would people still obey today? Am. Psychol. 64, 1–11.

Burkey, D., Anastasio, D., Bodnar, C., Cooper, M., [Video presentation]. STEM for All Video Showcase. May 5-12 2020. Collaborative Research: Experiential Process Safety Training for Chemical Engineers. https://stemforall2020.videohall.com/presentations/1691.

Butler, B., Anastasio, D., Burkey, D., Cooper, M., Bodnar, C., 2018. Work in Progress: Content Validation of an Engineering Process Safety Decision Making Instrument (EPSRI), Oral Presentation and Peer-Reviewed Proceedings , ASEE National Meeting, Salt Lake City, UT https://peer.asee.org/31279.

Butler, B., Bodnar, C., Cooper, M., Burkey, D., Anastasio, D., 2019. Towards understanding the moral reasoning process of senior chemical engineering students in process safety contexts. Educ. Chem. Eng. 28, 1–12.

Cooper, M., Stransky, J., Bassett, L., Bodnar, C., Anastasio, D., Burkey, D., 2020. Measuring student academic motivation toward process safety decision making within a digital immersive environment, oral presentation. AIChE Annual Meeting https://plan.core-apps.com/aiche2020/event/7d1b67152194cb166004d468df4d9894.

Cortés, J., Pellicer, E., ASCE, M., Catala, J., 2012. Integration of occupational risk prevention courses in engineering degrees: delphi study. J. Prof. Issues Eng. Educ. Pract. 138 (1), 31–36, http://dx.doi.org/10.1061/(ASCE)EI.1943-5541.0000076.

Craig, P., Oja, S., 2013. Moral judgement changes among undergraduates in a capstone internship experience. J. Moral Educ. 42 (1), 43–70, http://dx.doi.org/10.1080/03057240.2012.677603.

Crowl, D.A., Louvar, J.F., 2001. Chemical Process Safety: Fundamentals with Applications. Pearson Education.

Dee, S.J., Cox, B.L., Ogle, R.A., 2015. Process safety in the classroom: the current state of chemical engineering programs at US universities. Process. Saf. Prog. 34 (4), 316–319.

Derryberry, W., Thoma, S., 2005. Functional differences: comparing moral judgment developmental phase of consolidation and transition. J. Moral Educ. 34, 89–106.

Dholakiya, N.D., Ferjencik, M., Schofield, D., Kubík, J., 2019. Virtual learning for safety, why not a smartphone? Process. Saf. Prog. 38 (2), e12005.

Dixon, D.J., Kohlbrand, H.T., 2015. Lending industrial experience through reactive hazard examples in university safety instruction. Process. Saf. Prog. 34 (4), 360–367.

Hanna, L., Gillen, J., Hall, M., 2017. An investigation of final year pharmacy students' moral reasoning ability, and their views on professionalism and fitness to practice panel determinations: a questionnaire study. Curr. Pharm. Teach. Learn. 9 (4), 652–659, http://dx.doi.org/10.1016/j.cptl.2017.03.016.

Hassall, M.E., Lant, P., Cameron, I.T., 2020. Student perspectives on integrating industrial practice in risk and process safety education. Educ. Chem. Eng.

Hyten, C., Ludwig, T.D., 2017. Complacency in process safety: a behavior analysis toward prevention strategies. J. Organ. Behav. Manage. 37 (3-4), 240–260.

Kolhberg, L., Hersh, R., 1977. Moral Development: a review of the theory. Theory Pract. 16, 53–59.

Koretsky, M., Amatore, D., Barnes, C., Kimura, S., 2008. Enhancement of student learning in experimental design using a virtual laboratory. IEEE Trans. Educ. 51 (1), 76–85.

Krause, U., 2016. Process safety in engineering education – pro's and con's of two different approaches. Chem. Eng. Trans. 48, 871–876, http://dx.doi.org/10.3303/CET1648146.

Manenti, F., 2012. Natural gas operations: considerations on process transients, design, and control. ISA Trans. 51, 317–324.

Mayhew, M., Seifert, T., Pascarella, E., 2012. How the first year of college influences moral reasoning development for students in moral consolidation and moral transition. J. Coll. Stud. Dev. 53 (1), 19–40.

Mayhew, M., Pascarella, E., Trolian, T., Selznick, B., 2015. Measurements matter: taking the DIT-2 multiple times and college students' moral reasoning development. Res. High. Educ. 56 (4), 378–396, http://dx.doi.org/10.1007/s11162-014-9348-5.

Mildner, P., Mueller, F., 2016. Design of serious games. In: Dörner, R., Göbel, S., Effelsberg, W., Wiemeyer, J. (Eds.), Serious Games: Foundations, Concepts and Practices. Springer, http://dx.doi.org/10.7146/pas.v33i80.111719.

Milgram, S., 1963. Behavioral study of obedience. J. Abnorm. Soc. Psychol. 67, 371–378.

Mkpat, E., Reniers, G., Cozzani, V., 2018. Process safety education: a literature review. J. Loss Prev. Process Ind. 54, 18–27.

Nicaise, M., Gibney, T., Crane, M., 2000. Towards an understanding of authentic learning: student perceptions of an authentic classroom. J. Sci. Educ. Technol. 9 (1), 79–94.

Orvis, K.A., Moore, J.C., Belanich, J., Murphy, J.S., Horn, D.B., 2010. Are soldiers gamers? Video game usage among soldiers and implications for the effective use of serious video games for military training. Mil. Psychol. 22 (2), 143–157.

Osberg, T., Shrauger, J., 1986. Self-prediction: exploring the parameters of accuracy. J. Pers. Soc. Psychol. 51, 1044–1057.

Pascarella, E., Terenzini, P., 2005. How College Affects Students: A Third Decade of Research. Jossey-Bass Publishing, Inc., San Francisco, CA.

Pasinand, F., Giroux, H., 2011. "The impact of a simulation game on operations management education,". Comput. Educ. 57 (1), 1240–1254, http://dx.doi.org/10.1016/j.compedu.2010.12.006.

Philippas, D., 2014. Analysis of covariance (ANCOVA). In: Michalos A.C. Encyclopedia of Quality of Life and Well-Being Research. Springer, Dordrecht, http://dx.doi.org/10.1007/978-94-007-0753-5_82/.

Pintar, A., 1999. Teaching Chemical Process Safety: A Separate Course Versus Integration Into Existing Courses Paper Presented at 1999 Annual Conference , Charlotte, North Carolina https://peer.asee.org/7963.

Pitt, M.J., 2012. Teaching safety in chemical engineering: what, how and who? Chem. Eng. Technol. 35 (8), 1341–1345.

Radinsky, J., Bouillion, L., Lento, E., Gomez, L., 2001. Mutual benefit partnership: a curricular design for authenticity. J. Curric. Stud. 33 (4), 405–430.

Reiners, T., Wood, L., 2013. Immersive virtual environments to facilitate authentic education in logistics and supply Chain management. In: Learning Management Systems and Instructional Design: Best Practices in Online Education., pp. 323–343.

Rest, J., Thoma, S., Edwards, L., 1997a. Designing and validating a measure of moral judgment: stage preference and stage consistency approaches. J. Educ. Psychol. 89 (1), 5–28.

Rest, J., Thoma, S., Narvaez, D., Bebeau, M., 1997b. Alchemy and beyond: indexing the defining issues test. J. Educ. Psychol. 89 (3), 498–507.

Rest, J., Narvaez, D., Bebeau, M., Thoma, S., 1999a. A neo-kohlbergian approach: the DIT and Schema theory. Educ. Psychol. Rev. 11, 291–324.

Rest, J., Bebeau, M., Thoma, S., 1999b. DIT2: devising and testing a revised instrument of moral judgement. J. Educ. Psychol. 91 (4), 644–659.

Rest, J., Narvaez, D., Thoma, S., Bebeau, M., 2000. A neo-kohlbergian approach to morality research. J. Moral Educ. 29, 381–395.

Rodriguez, M.A., Bell, J., Brown, M., Carter, D., 2017. Integrating behavioral science with human factors to address process safety. J. Organ. Behav. Manage. 37 (3-4), 301–315.

Schonbucher, A., Brenig, H.W., Klais, O., Hauptmanns, U., Schmidt, J., Moritz, H., 2013. Model and curriculum. In: Process and Plant Safety., pp. 1–16, Frankfurt, M: Dechema.

Shepherd, A., 1986. Issues in the training of process operators. Int. J. Ind. Ergon. 1, 49–64.

Spicer, T.O., Willey, R.J., Crowl, D.A., Smades, W., 2013. The safety and chemical engineering education committee—broadening the reach of chemical engineering process safety education. Process. Saf. Prog. 32 (2), 113–118.

Stransky, J., Bodnar, C., Cooper, M., Anastasio, D., Burkey, D., 2020a. Authentic process safety decisions in an engineering ethics context: expression of student moral development within surveys and immersive environments. Australian J. Eng. Educ., http://dx.doi.org/10.1080/22054952.2020.1809881.

Stransky, J., Bassett, L., Anastasio, D., Cooper, M., Burkey, D., Bodnar, C., 2020b. Exploring Student Decision Making Trends in Process Safety Dilemmas Using the Engineering Process Safety Research Instrument, Oral Presentation and Peer-Reviewed Proceedings , ASEE National Meeting https://peer.asee.org/34645.

Swisher, L., Kessel, G., Jones, M., Beckstead, J., Edwards, I., 2012. Evaluating moral reasoning outcomes in physical therapy ethics education: stage, schema, phase, and type. Phys. Ther. Rev. Ethics 17 (3), 167–175, http://dx.doi.org/10.1179/1743288X12Y.0000000011.

Thoma, S., Rest, J., 1999. The relationship between moral decision-making and patterns of consolidation and transition in moral judgment development. Dev. Psychol. 35 (2), 1–16.

Throness, B., 2014. Keeping the memory alive, preventing memory loss that contributes to process safety events. Process. Saf. Prog. 33 (2), 115–123.

Vaughen, B.K., 2019. An approach for teaching process safety risk engineering and management control concepts using AIChE's web-based concept warehouse. Process. Saf. Prog. 38 (2), e12010.

Willey, R.J., Fogler, H.S., Cutlip, M.B., 2011. The integration of process safety into a chemical reaction engineering course: kinetic modeling of the T2 incident. Process. Saf. Prog. 30 (1), 39–44.

Willey, R.J., Carter, T., Price, J., Zhang, B., 2020. Instruction of hazard analysis of methods for chemical process safety at the university level. J. Loss Prev. Process Ind. 63, 103961.