Understanding Student Motivation to Engage in the *Contents Under Pressure* Digital Game

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Abstract. Game-based learning is an effective tool for motivating engineering students to engage with difficult and often complex topics. Although some research has been conducted on how games elicit motivation, additional studies have been suggested. The proposed work leverages Keller's ARCS-V theory to investigate how desire for a specific outcome within the process safety digital game *Contents Under Pressure* affects students' satisfaction or dissatisfaction with their experience. It was observed that students play the game with a desire either to improve themselves for internal satisfaction or to reach a set external objective in terms of academic or career performance. Many students also played the game with the goal to achieve key outcomes as it relates to game-based metrics. Students expressed a mixture of satisfaction and dissatisfaction with the outcome obtained. Those who were satisfied were most often exhibiting behaviors of paragaming or were experiencing immersion in the game, whereas those students that showed dissatisfaction often blamed the game while expressing difficulties with achieving a positive outcome.

Keywords: Game-Based Learning, Process Safety, Motivation.

1 Background

Since the early 2000s, game-based approaches have increased in popularity within engineering education. Most implementations in engineering have involved the use of digital games, as indicated by nearly a 3:1 margin over all other types of game implementations [1]. Literature reviews of game-based learning practices have highlighted the educational benefits of games, including increased motivation to engage with course material, although the need for further structured studies was identified [1, 2]. To leverage the benefits of game-based instructional approaches, a virtual environment that allows students to make process safety decisions called Contents Under Pressure (CUP) was developed. In this work, we examine how the desire to achieve a specific outcome in CUP motivates students to engage with the game. In a recent review on games and motivation, Grund [3] determined that there were 28 different motivational theories used to describe motivation and game play. We discuss three of the most-cited theories to provide necessary background for motivation studies that have been completed in game-based settings to frame our study.

The most frequently cited motivational theory as applied to games is Flow Theory [4], in which the participant experiences a state of absorption and engrossment in an activity that leads to intense engagement, immersion, and, in many cases, increased performance. However, the flow state can be challenging to establish, as it requires a careful balance between challenge and boredom. Flow Theory has been cited in numerous studies of motivation and digital games [5, 6].

The second most cited motivational theory was Self Determination Theory (SDT), as formulated by Ryan and Deci [7]. SDT is defined by three main components: autonomy, relatedness, and competence. Participants feel motivated when these three needs are met and feel discouraged when one or more are absent. *Autonomy* is chiefly concerned with the participant being able to exercise control over the situation. *Relatedness* deals with participants' connections to others, often a key component of multiplayer games. Lastly, *competence* deals with feelings of mastery afforded when performing tasks and achieving the goals in the activity. SDT has been discussed in the context of games and digital learning by numerous researchers in the literature [8, 9].

Another motivational theory is MVP Theory by Keller [10], which seeks to integrate motivation theory with other related constructs, such as volition and performance. This theory has important applications to game play, as volition incorporates the ideas of both *desiring* to act and the actual performance of an act through application of effort. The performance aspect incorporates the concept of feedback and aligning the participant's skill with the activity's objective. A positive or negative alignment generates different reinforcements and consequences, which contribute to the overall feelings of satisfaction or dissatisfaction. By incorporating volition and performance, MVP theory addresses two critical aspects of game-based activities beyond motivation alone: expending effort to convert thought into action, and providing feedback to the participant, which can influence continued motivation. Interestingly, Woo [11] notes that MVP Theory lacks significant investigation with respect to digital game-based learning.

Contents Under Pressure (CUP) is a digital game developed by the authors as a way for users to more realistically engage with the complexities present in process safety decision making. Process safety education is required in chemical engineering (ChE) curricula by the United States accrediting body ABET [12], in part due to continued chemical process safety incidents. Teaching process safety is challenging in that it is limited to a classroom environment because the risk of dangerous industrial situations prevents hands-on interaction and learning. In addition, many ChE programs teach process safety design skills, but often do not address decision-making aspects common with process safety incidents. A key advantage of using a digital game such as CUP for virtual process safety training is the game's ability to provide a realistic, immersive environment for process safety decision making training with low risk to the user and bystanders making use of a strategy known as preauthentication [13]. With its ability to provide competing goals, CUP has the ability to enable users to apply judgements that are more authentic and encourage them to make more realistic decisions [14, 15].

Even with the advantages of using digital games for process safety decision-making, there are few instances of digital games being used for this purpose. Often case studies such as videos offered by the U.S Chemical Safety Board (CSB) [16] or the Institution of Chemical Engineers (IChemE) [17] are required viewing in ChE curricula. While these videos and cases explain the real-life scenarios, they unfortunately either lack or limit interactivity. A key contrast between CUP and these other methods is that CUP's preauthentication strategy forces the user to make decisions about topics as varied as whether to allow a worker the day off during a critical period or whether to join their team for a morale-boosting lunch; the case studies focus only on critical safety decisions, which can introduce hindsight bias.

2 Theoretical Framework

After considering the elements of Flow Theory, SDT, and MVP Theory, ARCS-V theory was selected [18]. ARCS-V has as its core the ARCS motivational model [19]. Blending of ARCS and MVP was discussed with respect to digital game-based learning by Huang et al. [20], in which they describe this hybrid approach to better capture the feedback mechanism when participants learn from processing the outcome of the game. Keller's ARCS-V model has been used by other researchers to construct engaging and motivational content for digital courses and educational games [21, 22]. An adaptation of the ARCS-V model is shown in Figure 1.

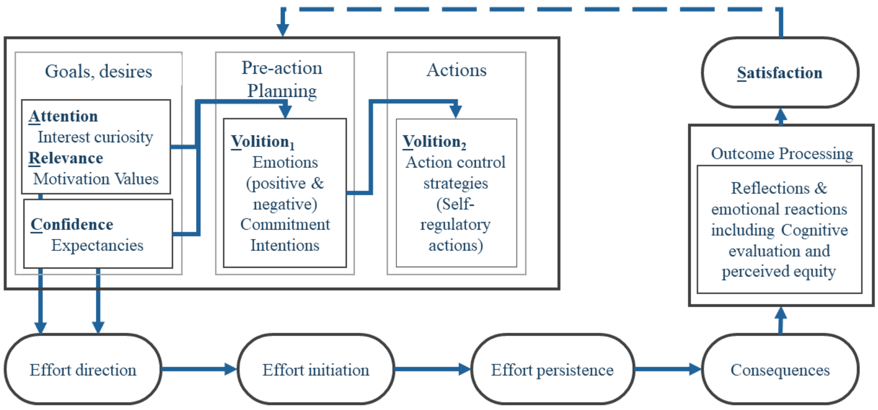

Fig. 1. ARCS-V model adapted from Keller [23].

ARCS consists of four categories related to motivation: attention, relevance, confidence, and satisfaction. *Attention* is similar to the interest/boredom/engagement concept discussed in Flow Theory, while *relevance* shares similarities with aspects of relatedness as discussed in SDT. *Confidence* is connected to expectations of success, which connects to a participant's own skills versus chance and reflects the competence aspect from SDT. *Satisfaction* relates to feedback, positive or negative consequences of actions, recognition, and fairness [23]. ARCS has at its root expectancy-value theory [24], which posits that people will be motivated by activities that have a high perceived value and a reasonable expectation of achievability. The ARCS-V model is a feedback loop that starts in the Goals and Desires box, where Attention, Relevance, and Competence (ARC) represent students' baseline motivation. Effort direction focuses on whether students' motivation is in a positive or negative direction. Effort initiation represents how intensely or quickly the outcome is pursued, while effort persistence represents the energy put into overcoming obstacles. The combination of these stages of effort lead to outcomes (consequences) which must be processed. Throughout gameplay, short-term outcomes are evaluated to determine if they provide satisfaction (S). Upon completion of this assessment, the evaluation of satisfaction is used to reevaluate the goals and desires. Satisfaction also impacts volition (V), which is how participants continue to put in effort amidst difficulties [23].

This study examines how the desire for a specific outcome in CUP influences an individual's motivation to participate in the game. Two research questions developed for this study are (1) "What range of outcomes do senior chemical engineering students desire to achieve in CUP?" and (2) "For students who found the final game outcome relevant, how did their outcome processing lead to satisfaction or dissatisfaction?"

3 Methods

3.1 Study Design

This study was conducted at four different universities within the United States. All participating students were in their final year of their chemical engineering program and were either enrolled in a senior design or process safety course. Students completed written reflections both before and after participation in CUP. CUP was an out-of-class assignment where students would earn credit for game completion, not based on their performance. Human subjects' approval was obtained for the study.

3.2 Contents Under Pressure

In CUP, students are presented with a series of relevant chemical process safety decisions and scenarios. Participants are placed in the role of a senior plant engineer that oversees three plant operators. They receive check-ins from their plant manager and safety inspector. Throughout the game, participants are required to make decisions that require balancing key metrics including safety, personal reputation, and plant productivity. If any of the key metrics fall to zero throughout the game, it results in a recorded player failure and the metric is reset for continued gameplay. The resulting values of all metrics and the recorded number of failures are used in the determination of the overall outcome presented to participants at the end of the game. Prior publications detailing the effectiveness of CUP have been published [25-26].

3.3 Data Collection and Analysis

Predetermined questions acted as reflection prompts promoting students to share in writing their perception of the overall game outcome and the relative importance of that outcome to their gameplay approach. Additionally, the reflection prompts asked whether students were hoping to obtain a specific outcome (pre-game) and whether they obtained the outcome they desired (post-game). The analysis only included students who completed both the pre- and post-reflections (n=225). Data collection and analysis was guided using the Walther et al. [27] research quality framework, which ensured that the results would be representative and transferable to other contexts.

A thematic analysis approach was used to address Research Question 1 [28]. Two researchers compiled all pre-reflections on potential game outcomes desired by students into a list. The researchers discussed this list identifying the underlying themes of desired outcomes and created a codebook describing the characteristics of major themes for the pre-reflection data set. The finalized codebook (refer to Appendix 1) was applied to a random sample of 25 pre-reflections to ensure mutual understanding of the codes. Level of agreement was determined through inter-rater reliability calculations, with discrepancies discussed prior to continuing coding to assure consistency. Once all responses were coded, the final inter-rater reliability obtained using Cohen's Kappa was 0.60 (moderate agreement) [29].

To address Research Question 2, pre-reflections were first provisionally coded to determine whether students expected the outcome to be relevant, irrelevant, or if they were indifferent [28]. Upon completion of this coding, 153 student reflections indicated the outcome would be relevant. Using this cohort, two researchers read their post-reflection responses to determine whether student opinion was expressed as satisfaction or dissatisfaction with their outcome. Satisfaction was determined based on decisive statements or by students' obtainment of their desired outcome following the ARCS-V model [18,23]. Students who did not specifically express either of these two opinions were removed, leaving 129 student responses to be thematically analyzed similarly to Research Question 1. Following this refinement process, the remaining responses were read by two researchers to identify themes that may have led to students' satisfaction or dissatisfaction with the final game outcome. This analysis produced a second codebook (refer to Appendix 2) that was used for thematic analysis of this subset of responses. Final inter-rater reliability for the thematic analysis was 0.53 (moderate agreement) [29].

4 Results and Discussion

4.1 Research Question 1

The first research question is *what range of outcomes do senior chemical engineering students expect to achieve in Contents Under Pressure (CUP)?* Through qualitative analysis, we identified six thematic codes: internal self-efficacy and improvement (15%), external self-efficacy and improvement (15%), metric preference (16%), metric balance (25%), desired or avoided an outcome (19%), and neutral or skeptical towards outcome (9%). Descriptions and examples of each are in Appendix 1.

The gameplay objective of CUP was to maintain the plant metrics throughout the narrative. The two codes related to this objective were metric balance, where two or more metrics were targeted to be balanced by the player, and metric preference, where a single metric was prioritized over the others. Metric balance was the most frequently observed code, and was best captured by Participant 25's reflection, "*The final outcome is important to me...I do hope that I can strike the right balance between* *the (...) main areas..."* Conversely, the preference of a single metric was best expressed by Participant 37, *"I definitely want to maximize the safety aspect, as this is very important to me. Obviously I would also like to have high scores on the other aspects as well, but I do realize that they might come at a cost to having a safe workplace."* There is value in practitioners knowing how to balance tradeoffs between professional criteria such as leadership, safety, time, and work-life balance [30-32]. For chemical process engineers specifically, incidents may occur from an imbalance of criteria, such as management [33], finances [34], or production quotas [35].

Another key finding related to desired outcomes focused upon Internal and External Improvement and Self-Efficacy. Responses that were related to the students' personal improvement, satisfaction, or betterment were coded as Internal Improvement, while responses that were related to improvement for the sake of career or academic performance were coded as External Improvement. Participant 14 provides an example of an internal improvement response, "*The final outcome will provide insight into my decision-making process and patterns. ...I really just want to understand how I make decisions and what I can do to improve my choices in the future."* Participant 73 expresses external improvement with their response, "*It is important that I do well to be sure I am making responsible decisions towards safety that could be applied in the real world during my career."* Also, Participant 191 reflects, "*I hope to receive a near perfect performance score for 2 reasons. Firstly, it is part of my grade and I want my GPA to remain as high as it possibly can. Anything but an A in this class lowers my GPA and so it is essential that I do well in every aspect of this and all of my classes..."* These codes align with intrinsic and extrinsic motivations of Self-Determination Theory [7]. Since this study was of students in various courses at several colleges, students were awarded with participation grades if they completed the simulation and submitted a final score as proof of completion. Some students sought a good outcome for that specific reason. This difference in approach highlights two ways the students could have viewed the game. The Internal response students may have looked at the game with the hope it could facilitate self-improvement, and the game's many choices granted them autonomy not seen in previous assignments. The External response students may have viewed the game as just another assignment. The balance between Internal and External responses might suggest that CUP's design struck a balance between perceived autonomy and evaluation, common drivers of intrinsic and extrinsic motivation [7].

4.2 Research Question 2

As applied to CUP, Keller's model suggests that players will process the consequences and rewards of their efforts to determine if they were satisfied with their experience. The second research question asks, *for those students who found the final game outcome relevant, how did their outcome processing lead to satisfaction or dissatisfaction*? Thematic coding of post-reflection responses identified six codes: concern for the game (through either Paragaming or Immersed Gaming) acknowledging difficulty (Difficulty), shifting blame or responsibility (Blame), responding emotionally (Emotions), and learning or changing from the game (Learning). Descriptions and examples of these codes are in Appendix 2. The distribution of code frequencies (Figure 2) first suggests Paragaming and Immersed Gaming were dominated by satisfied reflections, while Difficulty and Blame were dominated by dissatisfied reflections. Satisfied players may be more focused on the gaming experience, and dissatisfied players may be more focused on game traits, which prevented them from obtaining their desired outcome.

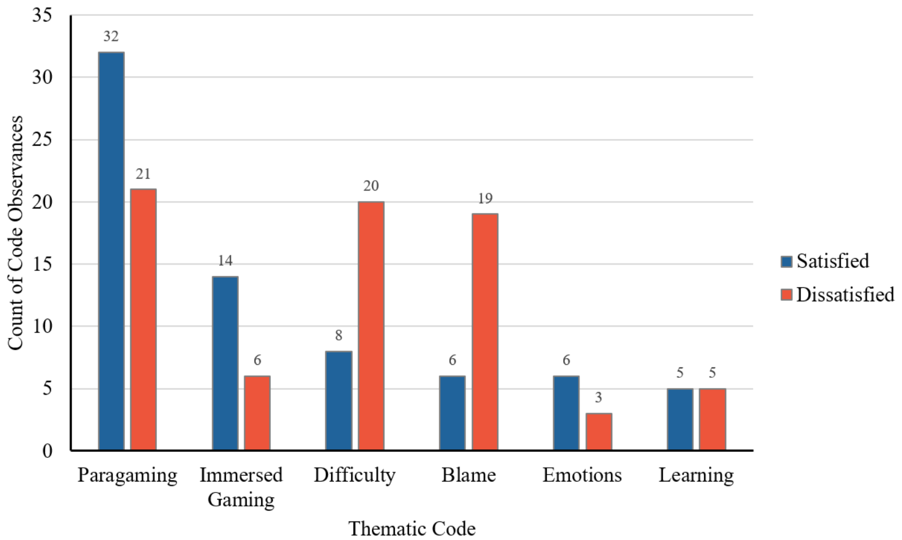

Fig. 2. Frequency of thematic codes on player satisfaction or dissatisfaction in CUP outcome.

Overall, the most frequent code was Paragaming, which describes a form of metagaming where the player may break character to pursue challenges and possible rewards as driven by their personal desires and motivations [36]. Also called "achievement hunting" [36], this approach can detract from a game's narrative. In the context of CUP, this code describes breaking from immersion to make decisions that are motivated to by game metrics, final score, or academic GPA. Participant 186 expressed dissatisfaction with the gameplay, "*I obtained my desired outcome but I was not satisfied with the process. Since I try to balance the 3 metrics, I made some decisions that I wouldn't make in real life. Therefore, I went against my will to avoid possible failure in any of the metrics.*" This reflection embodies paragaming, showing a strategy outside of their character in an attempt to obtain an achievement. The opposite response was seen with the reflection of Participant 74 who expressed satisfaction in their outcome while applying paragaming, "*I wanted a passing score and that's what I achieved! As long as I didn't fail the simulation, I would call that success...I think that an 80% is very satisfactory.*" Keller's model acknowledges that strategies are considered while processing an outcome [23]. It is possible some players found dissatisfaction specifically from processing their strategy. While paragaming can generate satisfaction, a participant's processing of their strategy does not guarantee satisfaction.

The Immersed Gaming code was developed to consider student responses that discussed the game through a more personal lens. Participant 14 expresses immersion in their reflection, "*My only desired outcome was not to get fired (or not have someone* *seriously injured or killed under my supervision). In this sense, I did obtain that outcome, but not with great success (workers still got injured)...”* In immersed responses, students do not explicitly refer to the game as a game; references to meters, inputs, graphics, or other words commonly associated with the game are minimal. Participant 14 shared that they do not want to get fired or injure employees - concerns that are possible if a player is immersed in the game. A number of responses reveal this level of immersion, with more students reporting that they were satisfied over dissatisfied in their immersed gameplay experience. Bormann and Greitemeyer found that in-game storytelling increased immersion and that players who were immersed were perceived to have made more meaningful choices and relationships [37]. Immersed participants in our study may have shared this experience, leading them to satisfaction overall. Participant 38 stated, “*I liked the aspect of failure, where then your team would step in and pull you back from the brink; it brought a more uplifting feeling to the game*.” Here, immersion resulted in a more positive experience despite failures. To explain the phenomenon of participants deriving satisfaction through immersion, we recall Csikszentmihalyi’s Flow Theory. While the framework was not applied directly in this study, Flow Theory suggests that players may become immersed when actively engaged and intrinsically motivated by a task [4]. The game may have allowed students to enter the flow of the narrative and helped them realize that their actions played a significant part in the game. They found satisfaction because, through immersion, the experience of the game was more motivating than the outcome.

Many student responses mentioned that the game was harder than they initially expected. These were coded as Difficulty. Participant 95 expressed this code well while acknowledging its impact on their performance, “*No, I wish I could have done better playing the game. At first I tried to just focus on safety and it caused my reputation and especially productivity to lag for the entire game until the end*.” The feedback loop in Keller’s ARCS-V model takes into account Learning and Performance [24]. Within the context of CUP, the students who found the game to be difficult may have begun to underperform due to perceived difficulty. As such, this underperformance may have played into their satisfaction feedback loop described in Keller’s model.

4.3 Study Limitations

These data were collected during the COVID-19 pandemic, possibly impacting how students interacted with CUP and influencing the results. Thus, replications of this work may find different results. The data were collected from only four US institutions, so these findings’ transferability may be limited. It should be noted that a standardized script was not used to introduce CUP in each classroom, so variations in description may have created some variation in students’ desired game outcomes.

5 Conclusion

This study sought to understand students’ outcome processing through application of the ARCS-V framework. Game outcomes desired by students included self-improvement, both internal and external, and balancing the game’s metrics. Overall, students expressed similar levels of satisfaction and dissatisfaction with the game outcome.

Paragaming was prevalent in students that expressed both satisfaction and dissatisfaction with outcomes. Dissatisfied students would often blame game elements or game difficulty for their outcome. Satisfied students would invest in the narrative, allowing them to become more immersed within the game. Overall, the study provided a more nuanced understanding of factors that may influence students' motivation to engage with a process safety game and identified areas in need of further study.

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Appendices

Appendix 1. Thematic code book used on pre-reflections to answer research question 1.

Code	**Sub-Code**	**Description**	**Example**
Improvement & Efficacy	Internal	Improving self for the sake of internal satisfaction, affirmation, or confidence in decision making.	"The final outcome will provide insight into my decision-making process and patterns. … and what I can do to improve my choices in the future."
	External	Improving for the sake of going into industry and obtaining a career or for obtaining a good grade/improving GPA.	"…if I want to pursue a career in chemical engineering, I want to be properly equipped with the knowledge of chemical process safety.... I hope to obtain a perfect performance throughout the game to ensure this education and confidence."
Criteria	Preference	Prioritizing or preferring one game related criterion over one or more other criteria.	"I hope to have a good center focus on safety over all else…"
	Balance	Attempting to balance or uphold two or more game related criteria equally	"I do hope that I can strike the right balance between the three main areas…."
Outcome	Desire / Avoidance	Pursuing a positive or avoiding a negative outcome of the game.	"I would want to minimize negative impact to all parties involved, with chief concern for employee safety."
	Neutral / Skeptical	Indifferent to potential outcomes or being skeptical about game's effectiveness.	"I'm not sure if the outcome will affect my approach."

Appendix 2. Thematic code book used on post-reflections to answer research question 2.

Code	Sub-Code	Description	Example
Acknowledge-ment of Complexity		Reflections recognize the difficulty students had with the decisions in the game.	"I was happy with my outcome on safety, but with personal reputation and productivity I was not pleased. Again, I found it difficult to balance these three so that all three are either neutral or positive.... I was conflicted at times when balancing between personal reputation and productivity because it felt like I had to choose one or the other."
Emotional responses		Reflections exhibit some form of emotional response in their reflection with regard to their performance: positive, negative, or neutral.	...I wasn't sure how I was going to be measured but looking back on the grade I got, **I'm happy with all of my choices for the most part and probably wouldn't change much doing it again.**"
Learning or changing in game		Reflections exhibit a change in perspective of process safety management from gained experience and learning.	"I would have like to have done better but I think the real take away was that you can't manage it all perfectly."
Score concern	Para-game	Reflections exhibit a concern with their performance and course grade which is manifested in concern for game score or number of failures.	"Yes. I finished with a small number of failures and scored a 98/100. **However, I obtained the scores I wanted by rigging the system in my favor, not by actually experiencing playing the game,** which tells me the system is not optimally designed."
	In-game	Reflections discuss balancing the in-game criteria as a responsibility of their management position, in addition to discussing whether or not they were fired at the end of the game.	"No, I was expecting to do better. But between the three sections I did about how I though I would relative to each other."
Shifting blame and responsibility		Reflections contain a denial of responsibility concerning their outcomes by passing responsibility to either game narrative or unrealistic attributes of the game.	"…I realized quickly that doing this flawlessly was nigh impossible...**this plant is very inefficient in the sense where if I'm not getting the task done I have a very limited group of people who can do it."**