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Decision-Making, Information Seeking, and Compromise: A Simulation Game Activity in Global Industrial Management

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Abstract

In undergraduate engineering education, students are often overexposed to problem-solving methods that are unrepresentative of how problems are solved in engineering practice. For decision-making problems in particular, students are commonly taught to compare alternative solutions using information that is known and provided. However, many real-world decision-making problems require a broader range of problem-solving strategies, including information seeking, extrapolation of a decision's consequences, and compromise between parties with competing objectives. Accordingly, this paper describes a simulation game activity designed to offer industrial engineering seniors experience in solving realistic decision-making problems. The simulation game involved students working in teams that role-played as different types of companies in a global smartphone market, where teams needed to negotiate with one another to establish profitable contracts within the game's ruleset. In accordance with our learning objectives, we qualitatively examined how students sought information, adapted to changing conditions, and made decisions informed by constraints. Particularly, we sought to identify learning frameworks that fit the data well and would help us improve the design and assessment of the activity in later iterations. We found that the learning frameworks of metacognition and discrepancy resolution combined to explain most student activity relative to our learning objectives, and these frameworks suggest several points of improvement for the design and assessment of the simulation game.

Introduction

Research shows a disconnect between academia and industry in terms of engineering education and practice (Johri & Olds, 2011). In particular, early career engineers believe that "engineering work is much more variable and complex than most engineering curricula convey" (Brunhaver et al., 2016). While engineering education continues to focus on the use of equations and theories to solve well-structured problems (Jonassen, 2014), engineering practice often focuses on skills needed to solve more ill-structured problems, such as problem formulation, communication, people management, decision-making, negotiation, and conflict resolution, among others (Brunhaver et al., 2016; Hazelrigg, 1998; Lagesen & Sørensen, 2009; Trevelyan, 2010; Williams, Figueiredo, & Trevelyan, 2014).

In our experience based on the first author's decade of experience working in engineering industry, exposing senior engineering students to problems that resemble the ambiguity and social characteristics of engineering practice reveals student difficulties in bounding, coping, and navigating through the ambiguity of problem definition. They display further difficulty in managing the complexity of dynamics associated with working with lack of information, operating in competitive environments, and incorporating uncertainty into engineering decisions. While engineers will eventually acclimate to this context during their early careers as practitioners, we believe that engineering education can be adapted to help our students gain those skills as they learn traditional concepts, theories, and analytical methods.

In this paper, we present the concept and initial research results of a team-based, role-playing simulation game that we employed in spring 2016 in a senior level course on global industrial management, offered as part of the Industrial Engineering curriculum at a large, mid-Atlantic university. The purpose of the simulation game was to adapt industrial and systems engineering concepts and methods to ill-structured problems. This purpose was translated to three main objectives. First, the game was aimed at fostering **information-seeking tendencies**, where instead of relying solely on assumptions about a problem, students would seek appropriate questions and ask them to the game masters (instructors) and other game players (student teams) in order to reduce ambiguity and uncertainty. Second, the game was designed to foster **adaptability**, where the boundaries of the solution space depended on students' ability to act in accordance with conditions that continually changed in response to competitors' actions. Adaptability involved managing uncertainty through negotiations with other teams and innovating within the game's ruleset to secure advantages. Third, the game was built to promote **constrained decision-making**, as students needed to understand what information was needed to apply certain engineering techniques or make engineering decisions, as well as distinguish which decisions were appropriate for the given amount of information and time they had to complete the game.

The purpose of this qualitative study was to identify evidence of learning during the game and to determine, for future iterations, (1) what learning frameworks fit the data to inform the game's design and assessment, and (2) what opportunities for improvement exist in the game's design. We thus focused our study on answering the following research questions:

1. How did learning manifest in students regarding the three learning objectives of information-seeking tendencies, adaptability, and constrained decision making?
2. Based on learning evidence, what learning frameworks would be well-suited as the basis for assessment and game redesign in future iterations of the activity?
3. What changes to the activity's design in future iterations might result in learning improvements?

The paper is organized as follows. First, we provide an overview of other interventions that have been used to accomplish similar goals in academia. Second, we provide a description of our methods, which includes the site where the intervention was conducted, the design of the intervention, the data collection process, and the data analysis approach. Then, we present the results of the intervention and provide a summary of the conclusions, implications, and recommendations for our planned next steps in this research direction. The results of this study are meant to inform a more thorough, mixed methods assessment of the simulation game's next implementation, as well as to refine and iterate the game's design.

Background

Contemporary engineering work primarily involved solving problems related to decision-making among alternatives, troubleshooting malfunctioning systems, and design, all of which require some level of ability in working with ill-structured problems (Jonassen, 2014). To encourage the development of this ability, several scholars have advocated for problem-based learning activities that foreground interaction with authentic, ill-structured problems (e.g., Dym et al., 2005; Jonassen, 2014). Simulation games—procedural representations of reality consisting of systems in which players engage in artificial conflict, defined by rules, that results in a quantifiable outcomes (Salen & Zimmerman, 2004)—represent one means of creating such activities. Scholars Gee and Hayes (2012) argue that games can be fundamentally understood as problem spaces, and the problems they contain can range from the well-structured spatial puzzles of *Tetris* to the ill-structured Rube Goldberg-type problems of *Contraption Maker* (Grohs et al., 2016). Moreover, these problems can be made sufficiently authentic if they are part of a simulation whose designers strive for high fidelity (Madhavan & Lindsay, 2014; Shuman, Besterfield-Sacre, & McGourty, 2005).

The simulation game we developed (described at the beginning of the Methods section) was preceded by several similar games that were designed, implemented, and documented within the last 30 years. Some notable examples include Cadotte's *Marketplace* simulation (Cadotte & Bruce, 2003; Stahl & Dean, 1999), Ammar and Wright's *Manufacturing Game* (Ammar & Wright, 1999), and Dudziak and Hendrickson's contract negotiation game (Dudziak & Hendrickson, 1988). The *Marketplace* simulation is intended for business student teams to integrate skills from several business disciplines by asking them to adapt to changing market conditions that react to their competitors' actions. *Marketplace* is still used in classrooms today through commercial software (Cadotte, 2016), but we felt it was not ideal for our goals because although it foregrounds constrained decision-making and adaptation in an ill-structured system, it does little to promote information-seeking tendencies or student interaction—at least in the published forms of its complete ruleset. The *Manufacturing Game* requires engineers to develop a full suite of long-term planning documents for a production planning and inventory control system, and to then implement and adjust this plan in reaction to a blitz of financial results during a single class period. The *Manufacturing Game* is used in another course of our industrial engineering curriculum, but we felt the need to develop a separate simulation game that better foregrounds adaptation to changing conditions and information-seeking tendencies. Finally, the contract negotiation game asks pairs of engineering student teams with competing objectives to come to an agreement on a single complex contract, requiring each to solicit information about the other team's goals and boundaries. While the contract negotiation game foregrounds information-seeking more than the other two games, we wanted to develop a game that incorporates negotiation in the context of a more ill-defined system over a longer period of time.

Our simulation game combines many of the features from the above games and also adds new features to fit our goal and context. Similar to *Marketplace*, we require students to adapt to competitor activity and market simulator results over several financial periods, but we encourage more interaction between teams and shed the focus on business skills. We encourage the types of negotiations foregrounded in the contract negotiation game, but require multiple simpler negotiations over several periods. Our game is quite dissimilar to the *Manufacturing Game* in structure and skill requirements, but requires similar attention to balancing product inventory and reacting to changes in product demand. Furthermore, we intentionally built ambiguity into some of the rules of our game to challenge teams to seek information about innovative strategies, which is a feature we did not see in any of the above simulation games.

Finally, our analysis method of identifying frameworks that fit student learning data attempts to abate a long-held habit in engineering education research to study interventions without respect to theoretical frameworks (Borrego, 2007). As there are many perspectives on learning and on what forms of learning should be considered valid (Newstetter & Svinicki, 2014), defining a framework helps to ensure that assessment aligns with the goals and context of the intervention being evaluated. For example, assessment-based research has devalued many existing simulation games based on observations that student retention of information did not significantly differ from lecture-based conditions (Druckman & Ebner, 2008). While these critiques are based on demonstrable evidence, frameworks of learning that value information retention are not likely to be compatible with the goals of many simulation games, which often revolve around higher order skills.

Methods

This qualitative research study examines student artifacts from the simulation game to infer information about how students went about pursuing each learning objective. This section describes the simulation game, enumerates the data we collected, and details our analysis approach.

Simulation Game

Overview. The game simulated a global smartphone market consisting of three types of companies: smartphone developers, manufacturers, and technology developers. Students formed teams that each represented one type of company. Smartphone development companies were the only teams to interact directly with the market by selling completed phones, but in order to do so, they needed to license phone technologies from technology developers and hire manufacturers to create the phones. Gameplay consisted of each team negotiating with other types of companies to create contracts and attempting to earn the highest profit among its company type. The game took place during the last seven weeks of the course, with each week representing an in-game "year" of activity.

Context. This game was employed as the final project in a senior level class on global industrial management. The course focuses on teaching how the practice of engineering changes in global industrial settings. It addresses elements such as political and regulatory constraints (import and export tariff and quotas), foreign currencies, applicability of foreign legal systems, working in multicultural environments, resolution of emerging ethical issues, and the impact of international strategies to the practice of engineering. The course had 80 students; approximately 60 students majored in Industrial Engineering and the rest of the students majored in Packaging Design, Biological Systems Engineering, or Mechanical Engineering.

Teams. Students were randomly assigned to twelve teams of six or seven students each. Each team was randomly assigned a company type such that there were four teams of each type.

Each type of company made decisions under different sets of constraints. Technology developers began with two (of a possible five) quality grades of technology they could license. Each team needed to pay a yearly maintenance cost to keep technologies up-to-date, lest they degrade to a less valuable quality grade. Manufacturers each started with the same capacity to produce phones, but depending on country of operation, each faced different costs for set-up, operation, and raw materials. Finally, smartphone developers were each required to offer at least two technology grades for sale, but to do so needed to successfully predict market demand and negotiate deals with manufacturers for production and technology developers for licensing. Furthermore, each team was competing with other teams of the same type during negotiations.

Each team received a document summarizing their initial conditions, which included the location of their company, products they have developed so far, yearly operational costs, and initial operational capacity. However, information about options to innovate was kept secret until companies explicitly sought such information from the game masters. For example, teams were not initially informed that technology developers could develop new technology grades, that manufacturers had the ability to increase production capacity, or that smartphone developers could advertise to increase market share.

Game Structure. The game was intentionally designed in a manner that encouraged students to collaborate with each other and also ask for information from other teams and the instructor. Companies were informed that they could not survive alone in the game. All teams were required to report decisions by submitting a document at the end of each week that included deals negotiated for the current year and plans for the next year. At the start of the next week, teams were then informed of the results of their deals (including their revenues, costs, and profits) via a personalized performance document. The game masters also published a weekly document that contained updated market information. Examples of both documents are included in the appendix.

In order to give all teams a chance to acclimate to the game's rules, explore possible strategies, and begin to build relationships through negotiations, the first two weeks of the seven-week game were denoted as "test years." During test years, students were able to see the results of their negotiations and strategies in terms of profits, but were also informed that profit would reset to zero once the test years were over. Thus, students were able to experiment for a short time with no risk of permanent loss if their strategies did not pay off. Once the game began in earnest in the third week, profits and losses accumulated until the game ended in the seventh week.

Game Simulator. Each team faced uncertainties regarding the factors affecting company performance. These factors included currency exchange rates, raw material prices, and market demand, all of which were randomly generated from predefined probability distributions. Another source of uncertainty was the potential governmental intervention in the market. For example, once the test years ended, teams were informed about a specific import tariff imposed on smartphones of grade A. By doing this, we intended to signal teams that such interventions are possible and need to be accommodated when making decisions and seeking information.

The market share of each smartphone developer was determined using a market-based model each year. Each company had a percentage of loyal customers based on their performance in previous years. This was in place to mimic the actual smooth demand shifts in the real world. Moreover, the overall market share was calculated based on the proposed price and technology grade of products that smartphone developers made available to the market.

Data collection

We collected three types of data through the game. First, we collected the weekly decision documents submitted by each team. While teams were informed that the documents only needed to include details of deals made through negotiation, the instructors specified that teams would be graded on how well they communicated their decision processes, and that these documents were a good opportunity to do so. Second, teams were allowed to submit an optional final report to supplement the weekly decision documents if they felt the need or desire to do so. Five of the twelve teams chose to submit a final report. Third, we recorded any questions that teams asked to the game masters by email. Use of these data for research was approved by our university's Institutional Review Board.

Data analysis

Data analysis took place in two parts. First, analysis of learning evidence to answer the first research question followed suggestions for variable-centered qualitative analysis procedures offered by Miles, Huberman, and Saldaña (2014). We began by open coding the data along four variables: (1) decisions made, (2) reasons for decisions, (3) information-seeking strategies, and (4) types of information sought in questions to instructors. With the exception of decisions made (which served to better help us understand the reasons for those decisions), we categorized the open codes of each variable into themes based on their similarities. Most of these themes were inducted from the data rather than a priori. Reasons for decisions were classified into two a priori themes (constraints vs. game variables requiring adaptation), but codes were then further grouped into inductive subthemes. These themes and subthemes allowed us to describe how our data addressed each learning objective.

The second part of data analysis followed suggestions for participant-centered qualitative analysis procedures outlined by Miles et al. (2014). Particularly, we created focused narratives called vignettes to capture important moments, decisions, and actions in each team's described gameplay experience. We constructed initial vignettes during data familiarization, reading through each team's documentation; noting important negotiations, strategies, and turning points; and then constructing a coherent narrative from these notes. Then, following the coding process, we used our codes for each team's decisions, reasons, and information-seeking strategies to further distill each vignette to a single paragraph that captured the key strategies and moments that appeared to define the team's experience.

In the process of constructing vignettes, we identified two learning frameworks that appeared to explain the data well. We then tested the frameworks against the data by using clustering to categorize which aspects of each team's experiences could be explained through each learning framework, and which aspects were not sufficiently explained by either framework. We concluded that the frameworks were explanatorily adequate when we identified that most aspects directly related to a learning objective were captured by the frameworks.

To improve the rigor of our study, we utilized techniques outlined by Anfara, Brown, and Mangione (2002). To improve our study's credibility (the qualitative correlate of internal validity), we utilized peer debriefing. Particularly, analysis was conducted by one author who was not part of the game's implementation or data collection process, and a summary of findings was presented to the authors who were involved in the implementation to ensure the results made sense from their experience. To improve our study's dependability (the qualitative correlate of reliability), we conducted researcher triangulation. Particularly, we conducted inter-coder reliability checks of our prominent code themes—particularly constraints, adaptations, and types of questions asked by teams—by asking another researcher to apply the themes to purposefully selected segments of the data. In the event of disagreement between coders, definitions of themes were revised until both coders agreed on their appropriate application.

Limitations

Our choice to allow teams to deliver the narratives of their experiences in their own way allowed us to analyze the data for an appropriate learning framework rather than imposing a framework we presumed might be effective. However, it also limited the kinds of analysis we could perform in at least three ways. First, no teams provided insights to intra-team dynamics, preventing us from seeing evidence of learning that occurred during team meetings. Second, some teams described their experiences more comprehensively than others; thus, the learning frameworks we selected may favor those students who told more detailed stories about their decisions and learning processes. Third, teams did not describe how they came to choose their initial strategies, which ended up being the most important decisions for some teams. It should also be noted that we only recorded questions asked by teams when they asked via email, and thus questions asked to instructors during class were not recorded. Despite these limitations, however, our analysis yielded fruitful results that helped us reconsider the game's design and assessment for future iterations.

Results and Discussion

Learning manifested in a variety of ways in student reports, but we found that most learning could be explained through the frameworks of metacognition and discrepancy resolution. This section describes the ways learning objectives manifested among teams, elaborates on the selected learning frameworks and how they fit the data, and uses these frameworks to enumerate several points of improvement for the game's design and assessment. Broader implications are also discussed.

Evidence of Learning

We found evidence of learning for all three of the game's learning objectives. Each objective will be described below with respect to the types of learning evidence identified. Because the primary purpose of this paper is to determine how the game's design and assessment can be informed by learning frameworks—rather than to demonstrate the game's effectiveness—we will refrain from offering detailed examples of learning evidence.

Information Seeking. Information about how students sought information during the game came from two sources: questions students asked through email to the game masters and descriptions of information-seeking through student reports. Of the teams who asked questions by email (10 teams), all eventually asked about the viability of innovative strategies. Most commonly, manufacturers and smartphone developers asked about ways to self-invest to improve capacity or market share, smartphone developers asked about creative ways to recycle leftover inventory, manufacturers asked about mergers with other manufacturers or supplier acquisitions, and technology developers asked about developing new technologies. Furthermore, the majority of teams inquired about the initial financial or operations states of their companies; requested information past, present, or future costs for particular actions; and asked for clarifications of particular game rules. All but one smartphone developer also requested information about market demand changes over time. We designed the simulation game to encourage all of these types of questions, and the data revealed that students recognized this encouragement and responded accordingly.

Comments on each team's information-seeking habits outside of the questions we collected were sparse throughout the reports, with only five teams including such remarks. However, these comments reveals both a variety of information-seeking approaches and reasons for using them. Students described probing for information through clever negotiation tactics (e.g., to find how much a company was willing to pay or to better read the state of the market), scouring the documents provided each week to determine the cause of their financial performance in a particular year, and turning to the instructors for advice as a last resort. We intend to redesign the game's assessment in future iterations to extract further detail about each team's information-seeking approaches.

Adaptability and Constrained Decision-Making. While the variety in strategies used and decisions made among teams was enormous, we were able to categorize nearly all reasons for team decisions as either adapting to a changing condition or operating within a specific constraint. Teams described decisions much more often with respect to adaptations than constraints. We found that adaptations were responses to at least one of the following variables: (1) offers from other teams and results from negotiations, (2) changes in the market or other teams' performance in the market, (3) activity from competitors, or (4) result's from the team's prior decisions. The majority of teams described adaptations to all of these variables—and all described at least one adaptation—but some variables were more prevalent in particular company types. For example, adapting to competitor activity was paramount to smartphone developers, who were constantly competing for market share, and to technology developers, who competed with one another to license particular technology grades. However, competitor activity was less of a concern to manufacturers, who focused instead on adapting to changes in phone demand on the market that affected their production, costs, and ability to negotiate with smartphone developers.

Constrained decision-making pervaded the entire simulation game, as teams were required to operate within the game's ruleset. However, constraints were less frequently discussed by teams when describing their decision-making processes than adaptations, perhaps because constraints were always in the background while variables requiring adaptation were more pressing. Nonetheless, nine teams described at least one decision made with explicit reference to one of the following constraints: (1) costs of an action, (2) amount of information available, (3) rules of the game, (4) initial conditions, (5) the game's time frame, or (6) constraints self-imposed through contracts with other teams. Like adaptations, constraints were addressed differentially by different company types. Technology companies, with their focus on profitable negotiations and high-cost technology development, most described being constrained by contract terms and costs. Smartphone companies also found themselves constrained by contract terms, but were more pressed by their initial conditions than costs, as some teams began the game with greater market share than others. Manufacturers, for some reason, rarely described constraints as informing their decisions.

While we were pleased to find copious examples among the data of productive decisions informed by variables and constraints, we also found a handful of variables and constraints that appeared to inspire teams *against* making productive decisions. For example, the game's time constraints inspired at least one team to not implement planned innovations or react to competitors in the game's last two years, presumably because they expected the game to end before they could reap any benefits from their actions. Moreover, the variability in negotiations inspired some teams to reduce risk by developing a lasting rapport with a single team, even if building that rapport meant accepting unfavorable negotiations. These teams were also more likely to maintain a deal even if their partner began to underperform and the deal became less lucrative. We noted these behaviors as counterproductive to the game's learning goal, and we intend to address them in future iterations.

Learning Frameworks

The learning frameworks that we selected to explain our data were metacognition and discrepancy resolution. We found that metacognition worked well to describe how teams decided upon a particular course of action given their situations and constraints. However, we found that metacognition was insufficient to explain how teams decided to take action (or not to take action) in the first place. For this explanation, we turned to discrepancy resolution. For the remainder of this subsection, we will introduce each framework using some background literature and offer a detailed example of how the framework explained our data. We intend our description of each learning framework to be functional, rather than comprehensive.

Metacognition. Metacognition is a learning framework that focuses on understanding and regulating one's own learning. While particular models of metacognition vary in their details, many contemporary models treat metacognition as a cycle that involves using one's metacognitive knowledge to select and regulate learning activities, which then allow one to update one's metacognitive knowledge (Ambrose, 2010; Cunningham et al., 2015). Metacognitive knowledge refers to three kinds of knowledge: (1) knowledge of self, particularly one's own strengths and weaknesses; (2) knowledge of tasks, including the requirements of a given task and what one needs to succeed in accomplishing a task; and (3) knowledge of strategies, encompassing different ways one could approach a problem (Cunningham et al., 2015; Flavell, 1979; Pintrich, 2002). These types knowledge are then applied to regulation of one's cognition, including planning an appropriate approach to a task, executing one's strategy, monitoring progress, and adjusting one's approach when necessary (Ambrose, 2010; Cunningham et al., 2015).

We found that this cycle of applying and updating one's metacognitive knowledge to regulate one's choice and execution of strategies explained well how teams selected and regulated their strategies in response to variables and constraints. As an example, we will present and analyze a vignette describing the experience of one of the manufacturing teams, *BoxCorp*.

> Excited to start—and hopefully win—the game, BoxCorp began by constructing an elaborate profit optimization model in which they could enter costs and previous demand to determine how many phones they should manufacture and for how much money they should sell each phone. They ran their model in the first performance year and negotiated with other teams accordingly. Everything seemed fine until they got their financial statement at the beginning of the next year. They expected positive profit, they ended up losing a lot of money instead.
>
> Perplexed, BoxCorp went back to their model and discovered that it did not account for tariff costs that were introduced, unannounced, in the first performance year. They adjusted their model accordingly, and determined that they needed the smartphone retailers with whom they partnered to pay the tariffs if BoxCorp was to make a profit. However, every smartphone retailer refused to do so, saying other manufacturing companies were willing to pay the high tariffs. Baffled at how other manufacturing companies could do this and still stay afloat, they decided not to produce in Year 2, and instead to seek help from the instructors to find a solution in Year 3.
>
> The instructors pointed out that BoxCorp's focus on their model had narrowed their vision and caused them to ignore other important aspects of the game. They were selling all their smartphones at the same low price, without realizing that the companies to whom they sold were willing to pay higher for phones with better technology. By the instructor's recommendation, BoxCorp discarded their model and instead focused on negotiating to find out how much smartphone retailers were willing to pay for different technologies. This move came a too late to dig them out of their negative profit by the end of the game, but their endgame performance was much better than when they relied on their model.

BoxCorp's approach revolved around using their model as a metacognitive tool. They developed the model using knowledge of the task at hand (i.e., costs and demand) and knowledge of optimization as an engineering strategy. When the model failed in the first year, BoxCorp evaluated its weaknesses and attempted to adjust their approach accordingly. Finally, when BoxCorp could not successfully negotiate away tariffs, they acknowledged that they would be wise to seek help and information from the instructors, who were able to help them refine their knowledge of their own weaknesses and plan a new approach accordingly. Of all the teams, BoxCorp's experience most clearly followed the cyclical process of metacognition, but we found that metacognition worked similarly well in explaining other teams' decisions.

Discrepancy Resolution. Discrepancy resolution is a theory stating that learning only occurs when there is a perceived discrepancy between an individual's expectations and perceptions of reality (Copple, Sigel, & Saunders, 1984). It is part of the constructivist learning paradigm, which asserts that people learn by constantly revising their mental models of reality by integrating new information with prior knowledge of how the world works (Brooks & Brooks, 1999). Thus, according to discrepancy resolution, if perceived reality does not conflict with one's existing mental model of reality, then the mental model needs no revision and thus no learning takes place. Importantly, discrepancies have to be perceived by the learner in order to be acted upon, as the learner cannot seek to resolve a discrepancy that he or she has not noticed (Copple et al., 1984).

Discrepancy resolution could help explain what spurred most teams to action, as many decisions were intended to reconcile differences between expected and actual profits—even the BoxCorp example above could be explained through the lens of discrepancy resolution. However, we find that such decisions are better explained through the more elaborative framework of metacognition. The value of discrepancy resolution is more evident when examining situations in which teams did *not* elect to make decisions due to information constraints. As an example, we will examine the experiences of all four technology developers.

Each technology developer approached the game with a different pricing strategy, as indicated in Table 1. Each strategy succeeded in covering basic technology maintenance costs, and thus each team generated a positive total profit. Some teams introduced an innovation now and then—such as developing a new technology—but each team's pricing strategy remained constant throughout the course of the game, and teams cited their positive profits as evidence for the strategy's success. However, as Table 1 displays, there was substantial profit variation between pricing strategies. Teams could not access information about other companies' profits, and thus their own performance was the only benchmark available. Because teams could not perceive the discrepancy between their profits and those of other companies using different pricing strategies, they were not compelled to resolve these discrepancies.

Table 1: Technology developer pricing strategies and performance

Technology Developer	**Pricing Strategy**	**Total Profit**
Technology Corp.	Charge a percentage of revenue for all phones sold of a licensed technology grade	$5,813 million
We Are Tech	Charge a percentage of profit for all phones sold of a licensed technology grade	$650 million
Glacier	Create long-term contracts, charging a flat rate that increases each year	$113 million
The Berg	Charge a flat rate that undercuts other technology developers	$75 million

Discrepancy resolution could be applied to similar situations in other teams, such as a manufacturing team that suddenly realized how inefficient its processes were after one of their partners persuaded them to try lean manufacturing. In any case, the underlying game design implication is clear: students need access to information and encouragement to pursue that information if they are to successfully detect and resolve discrepancies through adaptation and decision-making.

Points of Improvement

Game Assessment. We found that the weekly reports were helpful in familiarizing the game masters with teams' decision-making processes, and would like to continue this form of serial assessment. However, the prompts for these weekly reports should be more specific, and should align with the learning frameworks identified in our analysis. We propose that in each weekly report, teams should be asked to reflect on the following: (1) What discrepancies exist between expected and actual results of the previous week, (2) what strategies led to the discrepancies, (3) how were strategies adjusted to accommodate the discrepancies, (4) what information was needed to implement those strategies, (5) how they acquired that information, (6) how they went about implementing their strategies, and (7) the results of their strategy implementations. These assessments will not only provide a more structured way for instructors to understand how students are learning with respect to metacognition and discrepancy resolution, but will encourage students to engage in metacognitive reflection by communicating the value of such reflection (Ambrose, 2010).

Game Design. Our application of metacognition and discrepancy resolution to the data revealed several points of improvement for the game's design. From metacognition, future iterations of the game should ensure that the metacognitive cycle can proceed, unobtruded, through the game for all teams. One way to achieve this goal is to monitor teams' plans and ensure that no team locks themselves into a constraint that would impede the metacognitive process. For example, one technology team ended up committing themselves to long-term, exclusive contracts that they perceived as lucrative at the time, but later decided there were better alternatives available. However, because of their contract terms, they were unable to make any meaningful adjustments, effectively severing the cycle of metacognition and stifling learning. Game masters in future iterations could intervene to prevent these kinds of restrictive deals.

From discrepancy resolution, the game should provide students with the means and encouragement to access information necessary to detect and resolve discrepancies. We noted earlier that lack of access to other teams' profits caused the technology teams to not notice discrepancies between their ideas of a "good" profit and the profits achieved by more successful teams. This kind of information could be made available to teams in future iterations, either in financial reports or by request. Furthermore, as discussed in relation to game assessment, asking students to explicate their metacognitive process—including the information they may wish to seek—may encourage students to actively pursue information that would lead to a discrepancy.

Finally, we noted earlier that some constraints and variables inspired students to engage in counterproductive behaviors. While the effects of these constraints and variables were not captured well by our learning frameworks, they should nonetheless be mitigated in future implementations. For example, student decisions in later years could be incorporated in simulations of projected profits in years after the game ends, motivating students to continue making profitable decisions even when the game is almost over. Regarding teams who seem too attached to a single deal in the name of building rapport, the game's assessments could ask students to question the efficacy of current deals and propose changes in response, encouraging metacognition related to negotiation decisions.

Broader Contributions

In addition to informing the design and assessment of future game implementations, this study contributes to the industrial engineering education literature by offering an example of learning framework application to guide the interpretation of student learning in a student-centered learning activity. Use of learning frameworks to study student learning is of continuous importance to the field of engineering education (Borrego, 2007), but as we discussed in the Background section, assessments of simulation games tend forego frameworks. We hope that process can serve as a model for future faculty that assess and iterate novel activities by using learning frameworks as a guide.

This paper further contributes to the industrial engineering education community by introducing a simulation game activity that can be used to help students learn to make decisions in constrained, information-limited, and constantly changing global environments. We invite anyone interested in adapting this activity to their program to contact the first author for resources in implementing the simulation game.

Conclusions and Future Work

In this paper, we have presented an overview of a novel simulation game for industrial engineering students. We presented some evidence suggesting that students exhibited productive information-seeking habits and successfully made decision in response to constraints and changing conditions. More importantly, we identified two learning frameworks that explained students' learning experience well, and that can be used to collect more structured and descriptive learning data in future iterations. Finally, we used our analysis to identify several points of improvement to the game's design and assessment.

Our next steps include a second iteration of the simulation game in the spring 2017 implementation of the same course. We revised the activity in accordance with our findings in this study, and we will use the identified learning frameworks to collect data via a more well-defined assessment protocol. Our intention is to use data from the next iteration to formally evaluate the efficacy of the simulation game to promote student learning in accordance with the three learning objectives.

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Appendix

During the course of the game, all teams received a weekly performance document by the game masters. These documents were sent directly to the teams and were not shared between teams. The document included performance information such as revenue, cost, and their profit in the past simulated year. An example of such document is illustrated in Fig. A1.

Annual Report Company: Plantain [Company Pseudonym]

1. **Revenue Information**

Phone Type	Number of phones sold	Revenue
Grade A ($425)	2,600,000	$1,105,000,000
Grade B+ ($300)	15,840,000	$4,752,000,000
Grace C+ ($225)	2,700,000	$607,500,000

2. **Cost Information**

Item	Cost
Technology Patent Licensing Fee	$154,290,000
Manufacturing Cost	$10,155,000,000
Shipping	Paid by manufacturer
Import Tarriff	Paid by manufacturer
Operational Cost (10.05% of revenue)	$649,682,250
Efficiency Investment	$25,000,000

3. **Profit**

Your profit at the end of this year is -$4,519,471,250

Fig. A1. An example of the performance document generated for all teams.

Teams were also provided with another weekly document, summarizing the smartphone market statistics. This information was provided in the format shown in Fig. A2 and was shared between all teams.

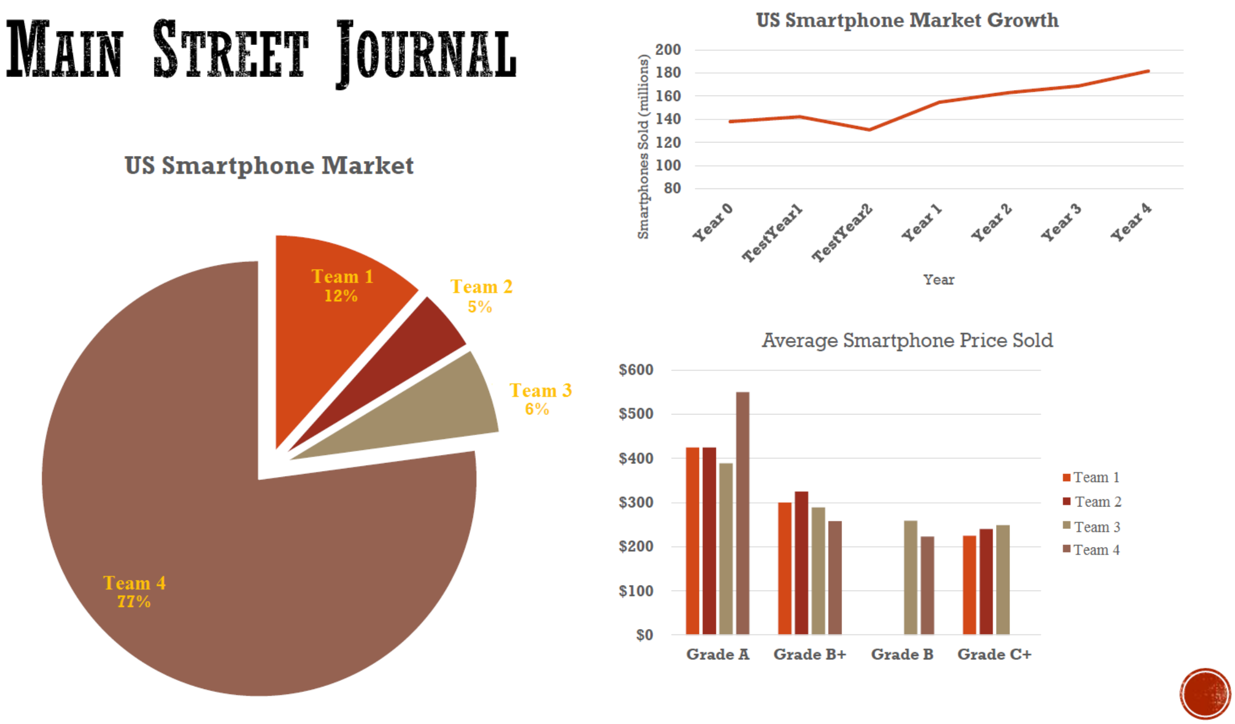

Fig. A2. An example of the document provided for all teams summarizing the smartphone market statistics. Team names have been redacted.