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# Board 195: A Comparison of an Integrated Nonlinear Storytelling and Simulation-Based Learning Game Module Assigned Outside-the-Classroom versus Inside-the-Classroom

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# A Comparison of an Integrated Nonlinear Storytelling and Simulation-Based Learning Game Module Assigned Outside-the-Classroom versus Inside-the-Classroom

## Abstract

This study investigates the contrasting effects of an outside-the-classroom format and an inside-the-classroom assessment format of an interactive nonlinear storytelling and 3D simulation-based learning game module. The pedagogical approach of integrating relatable story narratives within realistic simulation environments has shown to be an effective method for students to apply knowledge learned in a traditional classroom setting. Based on the findings of previous work, such applications encourage critical thinking beyond the classroom which better prepares students for their futures in the industry since most careers require increased application-based and critical thinking. For this experiment, two groups of students were introduced to the same nonlinear storytelling and simulation-based learning game module to assess their knowledge of inventory policies and queueing models. One group completed the assignment outside the classroom through a "flipped classroom" format, which was self-paced with no restriction on reference materials or time. In contrast, the second group completed the assignment inside the classroom as an assessment format, which included a time limit and restriction on reference materials being that students were not to communicate with one another or use resources outside their class notes and/or textbook. Upon completion of the assignment, both groups of students analyzed the same issues in the 3D manufacturing simulation while solving the same problems and proposing qualitative solutions to improve the overall system. Data was collected for the outside-the-classroom and inside-the-classroom groups in Fall 2021 and Fall 2022, respectively. The results of this study indicated no statistically significant difference in motivation, module usability score, engineering identity, self-assessment, or performance between the two groups.

## 1 Introduction

With the growing prevalence of online learning in today's society, it has become increasingly important for professors to ensure that lessons and class activities remain engaging and interactive for their students. Thus, the goal of this study is to compare the results of completing such activities outside the classroom versus inside the classroom.

For this study, two groups of Industrial Engineering (IE) students were assigned the same interactive learning game module that integrates both nonlinear storytelling and 3D-simulation learning techniques which was proven to increase learning outcomes in past experiments. The module uses a "choose-your-adventure" format (nonlinear storytelling) while also prompting users to interact with related simulations using the Simio® simulation software. Numerous characters are introduced to guide the user throughout the learning module, at the end of which the user is assigned a score out of 100 points based on responses to questions relative to the major educational topics of inventory policy (demand, annual cost, optimal order quantity, optimal reorder point) and queueing theory (product flow, bottleneck identification, load-balancing, utilization, availability, cycle time, work-in-process, throughput, waiting time). In a previous study, the integrated nonlinear storytelling and simulation-based learning game module reported the following statistically significant positive results [1]:

- Higher motivation (specifically *Attention, Relevance,* and *Satisfaction* constructs)
- Higher system usability compared to traditional case study format
- Higher performance compared to traditional case study format

For more information regarding the effectiveness of using the integrated nonlinear storytelling and simulation-based learning game module in an operations research course and related concepts, the reader is referred to [1].

In the previous study, the learning game module was conducted as an outside-the-classroom activity (Fall 2021). Over several weeks, students were given portions of the module to complete every week at their own pace, along with a workbook where students could document their work and submit their progress for grading. However, with the gradual return to in-person academic settings after the pandemic, the following question was developed: *What is the most effective way to implement this game module if given the choice between learning such material outside or inside the classroom?* It was hypothesized that the inside-the-classroom format (Fall 2022) could produce better outcomes as this format would require studying in preparation due to restricted resources when completing the learning module as well as prevent outside collaboration, ensuring that the students' work represented their individual efforts. Similar topics have been examined in prior research. According to Lee and Pruitt, with only a little extra effort by teachers, classroom assignments often produce a higher gain in student achievement [2]. This "extra effort" from being inside the classroom was reflected in this investigation through guidance from the professor and teaching assistants. Additionally, in an article referencing students' thinking during class instruction, Doyle stated that "the study of tasks in actual classroom settings can enrich our understanding" [3]. This further supports the notion that in-class assignments are necessary as without teacher support many students can become lost when working on their assignments which can be demotivating.

To test this hypothesis in the context of integrated nonlinear storytelling and 3D-simulation learning module, the experiment was implemented into the second Operations Research Course (IE 425: Stochastic Models in Operations Research) at Pennsylvania State University, the Behrend College during the Fall 2021 and Fall 2022 semesters.

## 2 Literature Review

Numerous studies have examined the effects of incorporating either nonlinear storytelling into curricula or the implementation of 3D simulation in the classroom. The knowledge gained from these studies is expanded upon in this work by merging simulation-based learning and nonlinear storytelling narratives into a single instructional tool and examining the results, particularly in engineering education. Prior research has shown that combining 3D simulation with nonlinear storytelling narratives can combine both the advantages of improving student engagement and closing the gap between theoretical knowledge learned in the classroom and actual engineering practices [1]. Moreover, hybrid education and flipped classrooms have become popular in the past few years as they overlap with the broader category of online learning which is the fastestgrowing trend in the use of technology for educational purposes. One of the current key areas of discussion in the education field is the comparison of the student's learning outcomes for assignments completed in class versus at home (outside class) via web-based assignments. While both methods have their own advantages and disadvantages, research has shown that there are some distinct differences in students' performance based on their location while completing the assignment. Caldwell has determined that the key advantage of completing an assignment at home is that the time barrier is removed which allows students to work at their own pace, which is proven to enhance the grasp of material for many students [4]. A study by Paul and Jefferson also indicates that online learners spend more time studying as they can access the class material and assignments anywhere at any time. It was also suggested that students tend to put more time and effort into completing online assignments as they are not restricted by the location or pressured by any immediate timeline [5]. In addition, Adam Butt has conducted a study by evaluating undergraduate college students' experiments with a flipped classroom setting during their final year of college. By the end of the semester, results indicated that 75% of the students viewed the flipped classroom setting as being beneficial to their understanding of the material and learning experience [6].

Furthermore, Bourhis and Burrell compared students' satisfaction between distance education and traditional classrooms. The results showed that while students tend to have a higher level of satisfaction when it comes to the traditional classroom environment, both teaching methods offer the same opportunities for academic improvement [7]. Bourhis and Burrell also researched the effects of different communication strategies via online communication, including video, audio, and written instruction, studying their impact on students' satisfaction. The results indicate that students' communication preferences depend on the amount of information communicated: when the amount of information is reduced, students prefer to communicate via video or audio. However, when the amount of information communicated is relatively larger, students prefer to receive written instructions [7].

However, while student satisfaction is a key factor in analyzing online activities and assignments, it may not directly be correlated to the teaching method's effectiveness. A study conducted by Bernard et al. determines the conditions that contribute to increased effectiveness in online learning. The study has shown that the most important aspect of online learning is the type of communication and interactivity used by instructors and indicates that the most effective teaching techniques are synchronous online learning, face-to-face learning, and asynchronous online learning respectively [8]. The main difference between the three types of teaching techniques is the difference in communication between the instructor and the students, which suggests that live or face-to-face instructions are more effective than an asynchronous delivery of instructions.

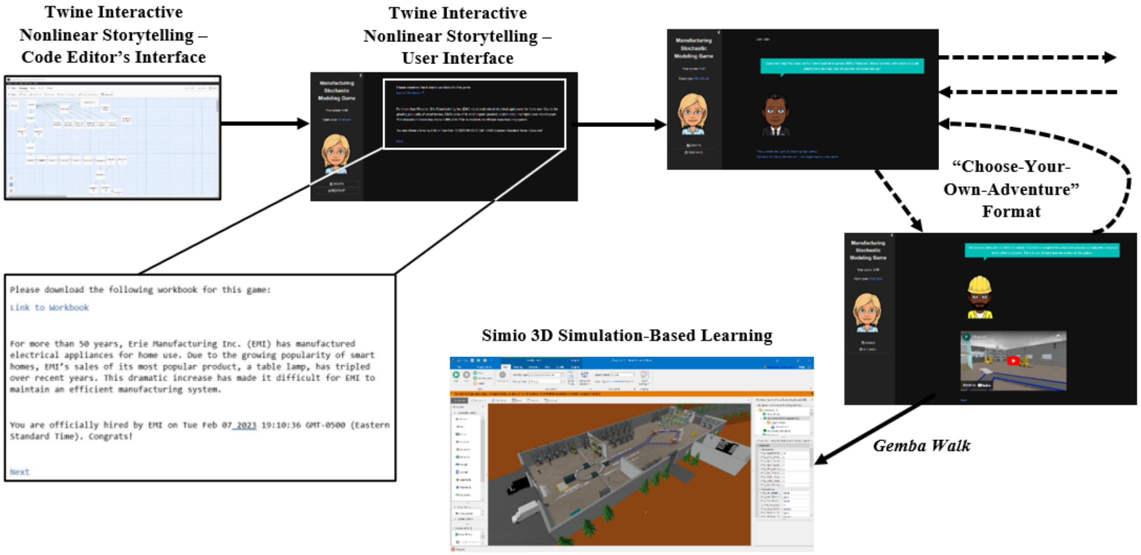
While many studies have compared the effectiveness of online learning and traditional learning, very few studies have explored the different outcomes of students' success when completing a traditional face-to-face assignment/activity in contrast to completing that same assignment outside class. The following experiment examines such effects in the context of an integrated nonlinear storytelling and 3D-simulation learning module assigned both outside and inside the classroom.

## 3 Background on the Nonlinear Storytelling and Simulation-Based Learning Game Module

### 3.1 Game Construction and Structure

The nonlinear storytelling and simulation-based learning game module was built using two software packages: Twine and Simio®. The nonlinear storytelling portion of the learning module was constructed using Twine, an open-source tool that allows for generating games in a "choose your path" nonlinear format, which are ultimately published in HTML format, resulting in increased accessibility [9]. For this learning module, Twine was used to create the story narrative, decisions/paths, questions, hints, and scoring system. The game's other software component is Simio®, which was utilized to create the 3D simulation models that students encountered when prompted to observe the system by visiting the system in a 3D virtual environment. These simulation visits are a substitute for visits to the actual system, commonly referred to in industry training and engineering pedagogy as "Gemba walks" [10].

The system involves the following simulated stations: order arrival at the facility, injection molding for a lamp base, preparation for lampshade assembly, assembly of the lamp base and lampshade, rework for defective assemblies, and packaging for shipment to customers. Images from the learning module are displayed in Figure 1.



Please download the following workbook for this game:

For more than 50 years, Erie Manufacturing Inc. (EMI) has manufactured electrical appliances for home use. Due to the growing popularity of smart homes, EMI's sales of its most popular product, a table lamp, has tripled over recent years. This dramatic increase has made it difficult for EMI to maintain an efficient manufacturing system.

You are officially hired by EMI on Tue Feb 07 2023 19:10:36 GMT-0500 (Eastern Standard Time). Congrats!

Figure 1. Screenshots from the interactive nonlinear storytelling and simulation-based learning game module

The learning objectives of the nonlinear storytelling and simulation-based learning game module include:

- Collect necessary data to improve the current system.
- Estimate certain quantities such as the demand for raw material.

- Analyze the current system and assess improvement opportunities.
- Evaluate the flow of parts in the system and devise a solution(s) to improve the performance of the system.
- Devise an inventory policy that minimizes the total annual inventory cost of raw material.

### 3.2 Relevant Coursework within Industrial Engineering Curriculum

The interactive nonlinear storytelling and simulation-based learning game module was implemented in the second Operations Research course within the Industrial Engineering B.S. curriculum at Pennsylvania State University, The Behrend College. This course covers the topics of Poisson processes, Markov chains, queueing theory, inventory theory, and dynamic programming and is a required senior-level course for students majoring in industrial engineering at Penn State. Of the topics listed above, the learning module focused on inventory models and queueing theory and was implemented into the course as a portion of the student’s final grade.

The storyline in the game was divided into ten days to simulate a walk-through of the daily life of a newly hired industrial engineer. The learning module was accompanied by a workbook that prompts students to record notes and findings as well as provide worked-out solutions to be graded. Both the score from the game and the workbook responses were used to grade the students’ work. Surveys were also collected after the students completed the learning module, along with individual interviews with the instructor at the end of the semester to evaluate each student’s understanding of the course concepts presented in the game.

## 4 Inside-the-Classroom vs. Outside-the-Classroom Experiment

### 4.1 Experimental Design and Measurements

Data were collected for two groups: Group 1 and group 2, referred to as outside-the-classroom and inside-the-classroom groups, respectively. The outside-the-classroom group’s data was collected in Fall 2021 and the inside-the-classroom group’s data was collected in Fall 2022. Both groups were assigned the same learning game module within the same Operations Research course taught by the same instructor. The major difference between the two groups was the environment in which the learning module was delivered, but secondary differences include 1) access/restricted access to outside resources, 2) onsite professor/teaching assistant guidance, and 3) time restrictions. The outside-the-classroom group was given no restriction on accessing external resources, no onsite guidance, and no time restrictions (other than the weekly deadlines). The inside-the-classroom group had restrictions imposed on accessing external resources such that only class notes and textbooks were permitted, onsite guidance, and time restrictions for the 50-minute class session. As mentioned previously, the group 1 game module was broken into six weekly assignments that were approximated to take 15-35 minutes each, spanning multiple weeks. In contrast, group 2 had the game module broken into three assignments that were estimated to take approximately 30-45 minutes each, spanning only three days during class time. Figure 2 shows the overall experimental design and implementation within this study.

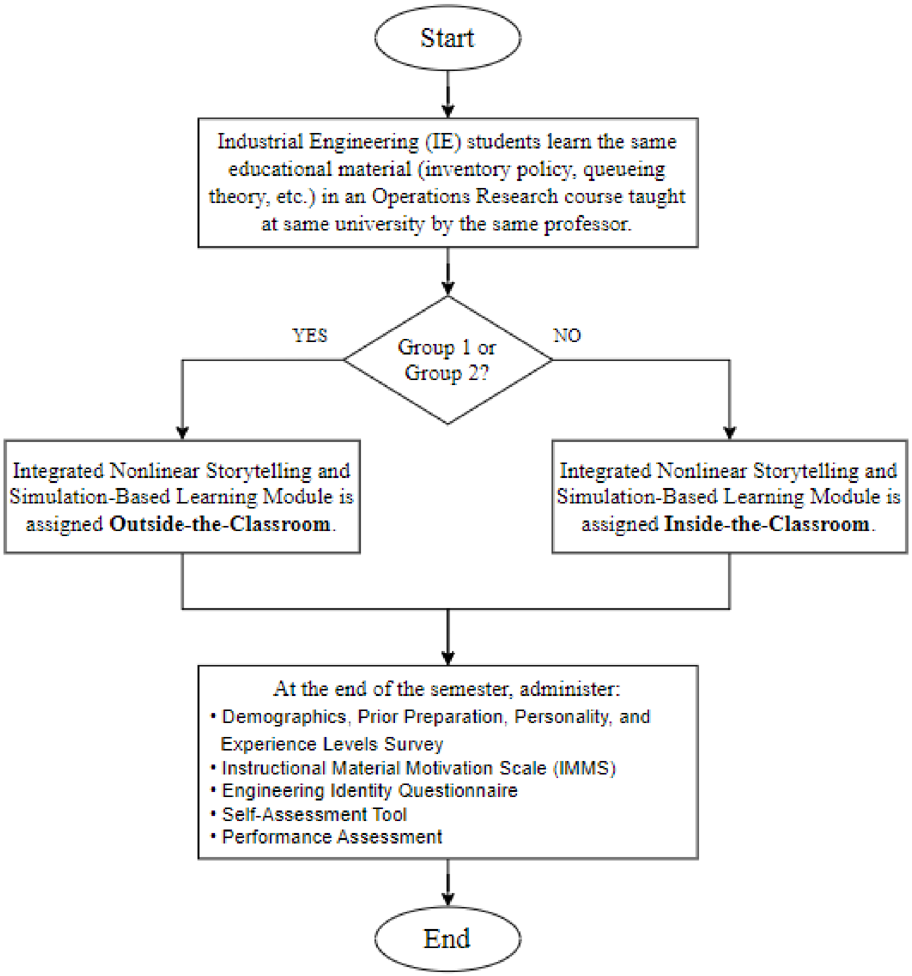


Figure 2. Experimental design and implementation

The instruments used to collect necessary data to ensure homogeneity among the two groups are listed below:

1) Demographic and prior experience and preparation: This survey collects the age, gender, race, prior preparation, and experience levels (i.e. GPA and prerequisite course(s), grade(s), semester standing, virtual reality (VR) experience, gaming experience, and Big-5 Personality Traits [11]).
2) Engineering Identity: This questionnaire measures how much a student thinks of himself/herself as an engineer. There are three constructs in this instrument: recognition (3), interest (3), and performance/competence (3) [12].
3) Instructional Materials Motivation Scale (IMMS): This instrument measures student motivation via four factors using the ARCS model: attention, relevance, confidence, and satisfaction [13].
4) System Usability Scale (SUS): This instrument measures the usability of the integrated interfaces with which the users interact during the learning module [14].

5) Knowledge self-assessment tool: This instrument measures a student's assessment of his/her own knowledge of the key concepts and learning outcomes. The self-assessment tool was constructed using the Revised Bloom's Taxonomy [15].
6) Performance assessment: This rubric was used to assess a student's performance and achievement of the learning outcomes.

### 4.2 Participants

A total of 31 students from Penn State University, The Behrend College participated in this study. The outside-the-classroom (i.e., group 1) group sample size was 17 students (76% male/24% female) who enrolled in the course during the Fall 2021 semester. The inside-the-classroom (i.e., group 2) group sample size was 14 students (57% male/43% female) who enrolled in the same course during the Fall 2022 semester. Both groups completed the same set of surveys and questionnaires (listed in the previous section). Students who did not complete the learning game module and/or survey were omitted from the analysis. Table 1 presents the summary statistics of the results for the demographic, experience, and personality questionnaires.

Table 1. Summary statistics of the demographics, experience, and personality questionnaires

| | Total | | Group 1 | | Group 2 | |
|---|---|---|---|---|---|---|
| | *Freq.* | *Prop.* | *Freq.* | *Prop.* | *Freq.* | *Prop.* |
| Gender Identity | | | | | | |
| Female | 10 | 0.32 | 4 | 0.24 | 6 | 0.43 |
| Male | 21 | 0.68 | 13 | 0.76 | 8 | 0.57 |
| Other | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Ethnicity | | | | | | |
| Caucasian | 21 | 0.68 | 12 | 0.71 | 9 | 0.64 |
| Hispanic | 2 | 0.06 | 1 | 0.06 | 1 | 0.07 |
| Asian or Pacific Islander | 6 | 0.19 | 3 | 0.18 | 3 | 0.21 |
| African American | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Other | 2 | 0.06 | 1 | 0.06 | 1 | 0.07 |
| Gaming Experience | | | | | | |
| None | 3 | 0.10 | 0 | 0.00 | 3 | 0.21 |
| Some | 16 | 0.52 | 8 | 0.47 | 8 | 0.57 |
| Expert | 12 | 0.39 | 9 | 0.53 | 3 | 0.21 |
| VR Experience | | | | | | |
| None | 7 | 0.23 | 3 | 0.18 | 4 | 0.29 |
| Some | 24 | 0.77 | 14 | 0.82 | 10 | 0.71 |
| Expert | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Big-5 Personality Trait[1] | | | | | | |
| Extraversion | 4 | 0.09 | 3 | 0.12 | 1 | 0.05 |
| Agreeableness | 14 | 0.30 | 10 | 0.38 | 4 | 0.19 |
| Conscientiousness | 16 | 0.34 | 7 | 0.27 | 9 | 0.43 |
| Neuroticism | 4 | 0.09 | 1 | 0.04 | 3 | 0.14 |
| Openness | 9 | 0.19 | 5 | 0.19 | 4 | 0.19 |

[1] Students who tied for two or more personality traits were counted in both trait categories. As a result, the proportion was taken from the total number of highest-scoring personality traits (including ties), which was not necessarily equal to the number of students in each group.

To test for homogeneity among the groups, a t-test ($\alpha = 0.05$) was implemented with results showing that the difference in the proportion of participants with different gender identities, ethnicity, VR experience, gaming experience, and personality traits was not statistically significant between the two groups. Moreover, the results of a t-test ($\alpha = 0.05$) indicated that the mean GPA of group 1 (M=3.27, SD=0.46) was not statistically significant from the mean GPA of group 2 (M=3.10, SD=0.54). As a result, it can be concluded that the outside-the-classroom and inside-the-classroom experimental groups were not statistically significantly different based on these measurements.

### 4.3 Results and Discussion

Table 2 shows the summary statistics of the Instructional Material Motivation Scale (IMMS), System Usability Scale (SUS) as well as the engineering identity questionnaire, knowledge self-assessment (based on Revised Bloom's Taxonomy), and performance assessment.

Table 2**.** Statistical analysis summary of the dependent variables

| | Group 1 | | | Group 2 | | |
|---|---|---|---|---|---|---|
| | *M* | *Mdn* | *SD* | *M* | *Mdn* | *SD* |
| IMMS[1] | | | | | | |
| Attention | 11.41 | 11 | 1.84 | 11.43 | 12 | 2.50 |
| Relevance | 12.88 | 13 | 1.41 | 12.36 | 12 | 1.78 |
| Confidence | 11.71 | 12 | 1.99 | 10.93 | 12 | 2.53 |
| Satisfaction | 11.64 | 11 | 1.73 | 10.57 | 12 | 2.44 |
| Overall = | 47.65 | 47 | 5.94 | 45.29 | 47.5 | 8.03 |
| SUS[2] | | | | | | |
| Overall = | 57.65 | 57.5 | 7.42 | 61.96 | 62.5 | 7.22 |
| Engineering Identity[3] | | | | | | |
| Recognition | 13.59 | 13 | 2.40 | 14.43 | 14.5 | 2.14 |
| Interest | 14.94 | 15 | 2.46 | 16.29 | 16.5 | 1.49 |
| Performance | 23.35 | 23 | 2.32 | 23.21 | 22 | 2.75 |
| Overall = | 51.88 | 52 | 5.24 | 53.93 | 52 | 4.48 |
| Self-Assessment[4] | | | | | | |
| Data Collection | 4.82 | 5 | 1.29 | 4.36 | 4.5 | 1.34 |
| Queueing Theory | 3.88 | 4 | 1.22 | 2.86 | 3 | 1.51 |
| Inventory Theory | 4.53 | 5 | 1.50 | 4.64 | 5 | 1.50 |
| Product Flow | 4.29 | 5 | 1.21 | 4.21 | 4 | 1.19 |
| Overall = | 17.53 | 18 | 3.56 | 16.07 | 16 | 3.81 |
| Performance Assessment | | | | | | |
| Overall = | 89.26 | 92.5 | 8.48 | 87.69 | 92.76 | 13.25 |

[1] IMMS questionnaire requires users to rate a set of 12 statements using a 5-point Likert scale. Each of the IMMS items are based on the responses of 3 statements (i.e., max= 15). IMMS is calculated based on the sum of all its items (i.e., max=60) [13].

[2] The System Usability Scale (SUS) questionnaire requires users to rate a set of 10 statements using a 5 point-Likert scale [14]. To obtain the SUS score of an individual, the responses are converted to numbers. The questions are counterbalanced (positive and negative). The responses are added accordingly and normalized to a 0-100 scale.

[3] The Engineering Identify questionnaire requires users to rate a set of 11 statements using a 6 point-Likert scale. The item of Recognition and Interest is calculated based on the responses of 3 different statements (i.e., max= 18), while the item of Performance is calculated based on the responses of 5 different statements (i.e., max= 30). Engineering Identify value is calculated based on the sum of all its items (i.e., max=66) [12].

[4] The groups completed a knowledge self-assessment instrument after submitting the assignment. The instrument was based on Bloom's revised taxonomy [15] and it allows the students to rate their knowledge on six levels (level 6 is the highest).

### *Instructional Materials Motivation Scale and System Usability Scale*

The results of a nonparametric Mann-Whitney test revealed no statistically significant difference between the two groups (p-value = 0.7348). The categories of Attention, Relevance, Confidence, and Satisfaction, as well as the overall IMMS score, were all compared with no significant change between the groups. These results indicate that students were no more nor less motivated when completing the interactive learning game module in different settings. In addition, there was no statistically significant difference in the learning game module usability between the two groups, also indicating that students did not have more or less difficulty when interacting with the interactive game module in different environments (p-value = 0.1194).

### *Engineering Identity*

The analysis of engineering identity was conducted using a t-test, which also indicated no statistically significant difference in engineering identity between the groups (p-value = 0.2581). The categories of Recognition, Interest, and Performance, as well as the overall engineering identity scores, were all compared with no significant change between the groups. Again, these results indicate students do not view themselves as more or less future engineers given the different settings in which they complete the interactive learning game module.

### *Knowledge Self-Assessment (using Revised Bloom's Taxonomy) and Performance Assessment*

Both groups also completed a self-assessment after submitting the interactive learning game module. This self-assessment instrument was based on Revised Bloom's Taxonomy for which students rate their knowledge from levels 1-6 (1=lowest; 6=highest) on the topics of Data Collection and Analysis, Queueing Models, Inventory Optimization, and Product Flow Improvement. Student performance was also measured through a grading rubric, in which students were given scores for the same categories of knowledge. Results from the t-tests show no statistically significant difference between the two groups for both self-assessment and performance (p-value = 0.2804 and 0.6911, respectively).

The correlations between performance and the other measurements were also analyzed, but none proved to be significant with values of $\rho = -0.1095$ and $-0.1079$ (IMMS), $\rho = -0.1462$ and $-0.2174$ (Engineering Identity), and $\rho = 0.2703$ and $0.3639$ (Self-Assessment) and for groups 1 and 2, respectively. However, when comparing the groups' normalized self-assessment and performance scores, both groups had a statistically significant between how they rated their knowledge of the material and the performance score (instructor grade) they received. It is hypothesized that students do not feel as though they are learning the material properly given the deviation from a traditional classroom setting for this interactive learning game module, however, more data and future research is needed to investigate whether this suggestion can be proven true.

### *Qualitative Analysis*

Upon submission, students were asked for changes they would recommend for the interactive learning game module if they were to use a similar learning module in their future classes. The most common suggestions were related to the game's interface, suggesting that an "*introduction* *to Simio*" or "*in-person tutorial*" would help ease the transition into the immersive environment. It should be noted that these items were prepared and distributed to students prior to the experiment, however, few students appeared to have prepared by studying the content ahead of time. The other frequent suggestion was related to the time given for the in-class assignment. This observation relates to the content discussed in the literature where students often prefer outside-the-classroom assignments for the decreased pressure associated with more flexible time limits. However, when reviewing the learning game module as a whole, positive feedback was also received. For example, one student said, "*This case study helped me visualize a production layout where some of the things we learned in class would be implemented in real life. Running the experiments helped me see the importance of the content we learned in this course and the effects it can have on companies' success…It helped me to understand that real-life problems will not be as clear and straightforward as in-class problems, and as an engineer, you must come up with solutions on your own.*" Another student said, "*After my first internship, I better understood the information I was learning in my classes and how I could apply it when I got a job after college. This case study was very similar to that experience and helped me engage with the class more.*" While this positive feedback is encouraging for the learning game module, this study aimed to compare student performance (not necessarily correlated to student preference) within a flipped classroom environment to traditional in-class settings, for which results suggested that when assigned an interactive learning game module such as this one, the setting in which the students complete the assignment does not influence their motivation, usability score, engineering identity, self-assessment of knowledge, nor overall performance.

## 5 Conclusions and Future Works

This paper evaluates the difference between students' motivation, usability score, engineering identity, self-assessment of knowledge, and overall performance when an interactive nonlinear storytelling and simulation-based learning game module is implemented in a traditional in-class environment and a flipped classroom setting. The learning module combines a nonlinear story narrative and 3D simulation-based learning. The study data was collected in the second Operations Research course of the Industrial Engineering curriculum at Pennsylvania State University, The Behrend College. Two groups were used in this study, both of which were taught the same material and taught by the same instructor. Moreover, both groups were exposed to the same nonlinear storytelling and 3D simulation-based learning game module. Group 1 worked on the learning game module outside of class while group 2 worked on the learning game module in class in the presence of the instructor.

The results of the study show that there was no statistically significant difference between both groups for any of the measurements. Therefore, for this context, the interactive storytelling and simulation-based learning module can be implemented in any setting without negatively impacting students' motivation, usability score, engineering identity, self-assessment, or overall performance. The results are promising as these learning game modules could potentially be used in online/remote classes without compromising students' quality of education, which is beneficial since the modules are electronic, portable, and accessible by students anywhere.

Due to the limited differences revealed between the two groups, some limitations are worth mentioning. The validity of the conclusions can be enhanced by increasing the experiment sample size. Furthermore, other metrics could be considered such as the difference in the time it took the students to complete the assignments or the difference in costs for the two teaching methods.

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