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A Study on the Effectiveness of using Integrated Nonlinear Storytelling and Simulation-based Learning Game in an Operations Research Course

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Abstract

This study investigates the effectiveness of using a learning module that combines interactive nonlinear storytelling games with three-dimensional (3D) simulation models. The story narrative is used to mimic real-world scenarios to train students to apply their knowledge. Using simulation software and games can facilitate practical understanding of complex systems and enhance students' learning outcomes via situated learning. Situated learning is a pedagogical approach that places learners in real-life problem-solving situations to foster meaningful STEM learning. In this work, students use a nonlinear story to represent and express what they know about inventory and queueing models. Students use the simulation models to examine, analyze, and access virtual worlds that mimic real-world systems, interpret the information, organize their knowledge, and represent what they have learned.

To investigate the effectiveness of combining nonlinear storytelling & simulation-based learning on students' learning and motivation, two groups are compared: control (simulation-based only) (1), and intervention (nonlinear story and simulation learning game) (2). The control group is composed of students who used simulation models with a traditional case study format. In comparison, the nonlinear story and simulation learning game group is represented by the students who are taught with the aid of the game learning module. The results of this study compared the groups in terms of students' motivation, engineering identity, and learning outcomes. The data of the control and intervention groups were collected in Fall 2020, and Fall 2021, respectively. The intervention group showed higher overall motivation and learning outcomes compared to the control group.

1. Introduction

This paper presents the results of the integration of nonlinear storytelling games with simulation-based learning in Industrial Engineering (IE) coursework. For this study, 3D simulation is defined as a representation of a known process within reality using appropriate constraints such that predictive analysis can be performed on the system [1]. Additionally, nonlinear storytelling is defined as a method of digital storytelling using interactive plots such that not all users follow the same path due to multiple branches [2]. Both of these elements are considered beneficial as they address the problem of declining student engagement and the lack of connection between traditional teaching methods and real-life engineering problems. The challenge of student engagement has become crucial with the recent shift to a higher dependency on online learning [3]. This shift to remote instruction has also caused concerns regarding the knowledge gap between theory taught in a classroom setting and real-world practices that students are expected to encounter upon graduation. Thus, the goal of this study is to determine if integrating nonlinear storytelling and simulation-based learning into traditional IE coursework can produce better learning outcomes as well as increase student motivation and engineering identity.

The 3D simulations are created using a simulation software called Simio, in which a virtual system is constructed to simulate a realistic manufacturing system [4]. The system is created such that it is complex enough to simulate the challenges an industrial engineer would face in a real-life manufacturing facility. The nonlinear storytelling is created using a software called Twine, an open-source tool that allows for interactive and nonlinear stories to be published in HTML format, leading to increased accessibility and portability [5]. Nonlinear storytelling uses the "choose-your-adventure" format in which the player walks through exercises and makes decisions while numerous characters are introduced to guide the player throughout the game. The story was also designed to implement a scoring system to track user performance. This scoring system is weighted out of 100 total points, and points are allocated based on the difficulty of the challenge in the game, ranging from 0-10 points. The critical challenges for this game included scenarios related to inventory policy (demand, annual cost, optimal order quantity, optimal reorder point) and queueing theory-related scenarios (product flow, bottleneck identification, load balancing, utilization, availability, cycle time, work in process, throughput, waiting time). Some additional points were given for correctly defining problems within the system and proposing potential solutions, as well as making final recommendations to improve the system. The game was implemented in the second course of Operations Research (IE 425: Stochastic Modeling in Operations Research in industrial engineering (IE) at Penn State University, The Behrend College) for testing the effectiveness of integrating nonlinear storytelling and simulation-based learning in an operations research course.

2. Literature Review

Several studies have investigated either the effects of implementing 3D simulation or the effects of integrating nonlinear storytelling into educational curricula. This work builds upon the knowledge derived from these studies by combining both nonlinear storytelling and simulation-based learning into a single educational tool and observing its effects, specifically in engineering education. It is hypothesized that the combination of 3D simulation and nonlinear storytelling will leverage both the benefits of increasing student engagement and reducing the gap between classroom theory and real-world engineering practices.

Situated learning is a contextual learning theory focusing on the impact of physical social, and cultural factors on learning. Situated learning theory posits that learning is improved when students take part in real-world situations and engage with real-world problems [6]. When students learn in the environment in which they are expected to apply their knowledge, they practice transferring that knowledge. Transferring knowledge from school to the real world is often a challenge for students as they do not immediately see how factual information translates to the real-world problems they encounter [7]. Because the spontaneous transfer is infrequent, time must be spent explicitly teaching students to transfer knowledge to new problems. In fields such as teaching, medicine, and manufacturing, opportunities to practice applying knowledge and skills to real situations are vital to success. While many fields require an internship-type experience for learners to practice using knowledge in real scenarios, the development of computer-based simulations can expand these experiential opportunities [8] allowing them to occur much more frequently. Simulation-based games can also train thinking skills, helping students focus on important parts of a problem, monitor the impact of their decisions, make multiple attempts on a problem, and, overall, assist in efficacy development [9]. Interactive simulation games can even provide in-the-moment support for beginners and fade this support as students' performance improves.

Simulation allows users to be immersed in a learning environment where theoretical knowledge can be deepened through actual experiences. Additional opportunities within simulation include increasing intrinsic motivation and decreasing risk avoidance. According to the analysis of simulation-based education, simulation can serve an especially important role in encouraging students to pursue STEM education [10]. Simulations can be designed effectively such that they challenge players, thus providing satisfaction when a goal is achieved, as well as providing assistance to avoid frustration. Research has also suggested that simulation-based education minimizes risk as students learn in a synthetic environment that is controlled yet realistic, thus avoiding safety concerns and expensive mistakes [1]. However, perhaps the greatest benefit to simulation-based education is the connection established between classroom theory and real-world practice, a connection that is often lost within traditional teaching methods due to the oversimplified and/or unrelated content [11]–[18]. Other fields of education have experienced positive outcomes, especially in healthcare education. For example, a study concluded that nursing students who were exposed to simulation-based learning found their experience to be more reflective, practical, and engaging [19]. Similarly, another study found that learning in virtually simulated 3D worlds is not only associated with improved student engagement in the learning process but also associated with limited advances in knowledge gain [20]. It is important to note that other 3D simulation studies similar to the examples above have been performed across different disciplines. The majority of these studies yield the same results of positive emotional outcomes, such as increased engagement and motivation, but with either a small or no influence on student knowledge and understanding. There is a distinct lack of investigating the influence of integrating nonlinear storytelling and simulation-based learning games in engineering education. Thus, there is a great opportunity for investigating the effects of this combination within modern engineering curricula.

Storytelling is quite common across many undergraduate disciplines, however, almost all storytelling used in traditional educational settings has a linear format [2]. Such examples include case studies where exercises are presented in a predetermined order with information that does not change regardless of student performance. However, studies have shown that integrating nonlinear formats as a pedagogical approach can have a positive effect on students' attitudes and retention. In 2018, a study conducted an experiment in which students faced a management hiring problem scenario of nonlinear format [21]. The results suggested that students responded with positive emotion to the nonlinear storytelling method because it instilled a sense of responsibility and autonomy through providing the opportunity to explore alternative solutions, thus supporting student engagement and problem-solving skills. Additionally, another study concluded that students who experienced nonlinear storytelling compared to traditional teaching methods were 52.7% more motivated, 65.2% more interested in in-class activities, and participated 73.9% more in the classroom [22]. Similar to 3D simulation studies, the emotional responses of engagement, motivation, and participation were overwhelmingly improved in nonlinear storytelling studies, but uncertainty remains regarding whether knowledge and understanding improve as well.

3. Effectiveness of the Interactive Nonlinear Storytelling and Simulation-based Learning Game

3.1 Nonlinear Storytelling and Simulation-based Learning Game Module

The interactive nonlinear storytelling and 3D simulation-based learning game module is built using Twine and Simio®. Twine is used to create the nonlinear storytelling game. In other words, it is used to create the story narrative, decisions and paths, questions, hints, and scoring system. On the other hand, Simio® is used to create the 3D simulation model that the students use as a way to visit, observe, experiment with, and study the system. The simulation visits are a replacement for visiting an actual system, i.e., Gemba visits. The simulation model is built for a table lamp manufacturing system [15]. The system involves the following process/steps: Order arrival, injection molding for the base part of the lamp, base part cooling over a conveyer built, assembly preparation, assembly of the base part and the lampshade, rework for defective assemblies, packaging, and finally shipping. The base parts of the table lamps are produced in-house, while the shades are outsourced. A portion of the game environment is shown in Figure 1.

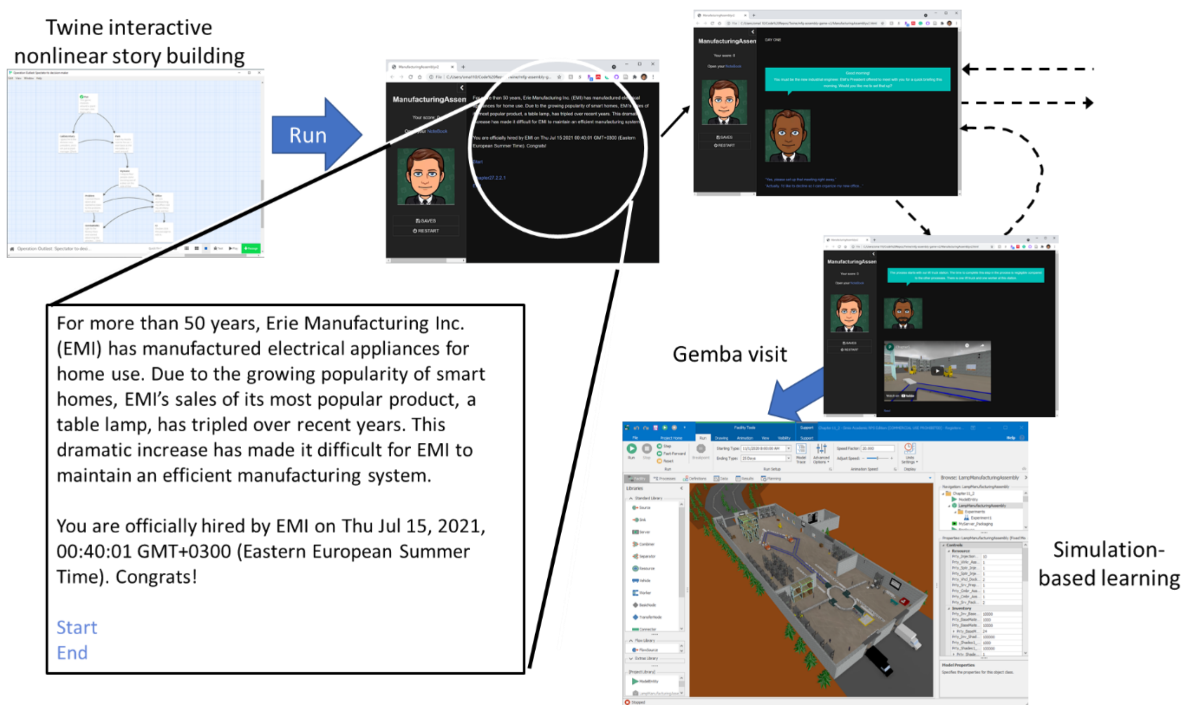

Figure 1. Interactive nonlinear storytelling and simulation-based learning game module

The learning objectives of this learning game module are:

- 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 the 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.

For more information about the system and related concepts, the reader is referred to [15].

3.2 Course

The game was implemented in the second course of Operations Research (IE 425: Stochastic Modeling in Operations Research) in the IE curriculum at Penn State University, The Behrend College. The course introduces Poisson processes, Markov chains, queueing theory, inventory theory, and dynamic programming. The course applies these models to manufacturing and service systems. It is a required IE course that is taken by the upper-level students in the department. The main topics implemented in the learning module are queueing theory and inventory models. The game learning module is implemented as a case study in the course, and the timeline of the game was divided into ten days (some days are combined due to introductory material and this resulted in 6 sections in total). The days represent a walk-through of the daily life of a newly hired industrial engineer. The game module is accompanied by a workbook that prompts the students to record notes and findings and provide their worked-out solutions. The workbook along with the score from the game are used to grade the student's work. Students submit their progress weekly. User data from the game including the student clicks/decisions, time spent on each page, hints used, number of attempts, and answers are also collected and can be exported as a .csv file. Surveys are also collected after the students submit the last milestone/report of the case study. Moreover, the instructor interviewed the students individually at the end of the semester to verify and assess students' understanding of the concepts.

3.3 Study Experiment

3.3.1 Experimental Setup and Instruments

The team collected data for two groups: control and intervention groups. Both groups were taught the same material and by the same instructor. The control group data were collected in Fall 2020, while the intervention group data were collected in Fall 2021. Both groups received the same case study. The main difference between the groups is the way of delivering the case study. The control group was given a traditional case study with a 3D simulation of the table lamp manufacturing system (see [15]). The intervention group was given the interactive nonlinear storytelling and simulation-based learning game module instead of the traditional case study. Figure 2 shows the overall experimental design and implementation followed in this study. Figure 2 also shows the instruments used to collect the necessary data to make sure the groups are homogenous and to compare the groups with respect to motivation, engineering identity, and achieving learning outcomes. The control group was given 5 weeks to finish the case study while the intervention group was given 6 weeks. More time was given to the intervention group because the first couple of days (in the story) were used to introduce the system and the game to the students. The following list briefly describes these instruments.

1) Demographic and prior experience and preparation: This survey collects the age, gender, race, prior preparation, and experience levels (i.e., GPA and the prerequisite course(s) grade(s), semester standing, virtual reality (VR), and gaming experience levels, Big-5 personality traits [23]). This information was collected to test the groups' homogeneity for statistical comparison.

2) Engineering identity: The instrument provides information on how much a student think of themselves as an engineer [24]. There are three constructs in this instrument, i.e., recognition (3 items), interest (3 items), and performance/competence (5 items) [24].
3) Instructional Materials Motivation Scale (IMMS): This instrument is used to assess students' motivation. The instrument has four factors according to the ARCS model, i.e., attention, relevance, confidence, and satisfaction [25].
4) Self-assessment tool: The instrument is built using the revised Bloom's Taxonomy [26]. The instrument is provided to the students to assess their understanding of key concepts and learning outcomes.
5) Performance assessment: This is a rubric that is used by the instructor to assess the student's performance and achievement of learning outcomes.

3.3.2 Participants

A total of 38 students from Penn State University, The Behrend College participated in this experiment. The simulation-based group (i.e., control) was composed of 20 students (55% males) who registered for the course during the Fall 2020 semester. Lastly, the nonlinear story and simulation-based learning game group (i.e., intervention) was composed of 18 students (78% males) who registered for the same course during the Fall 2021 semester. The students in both groups completed a series of surveys and questionnaires (see Figure 2). Table 2 shows the summary statistics of the results from the demographics, experience, and personality questionnaires.

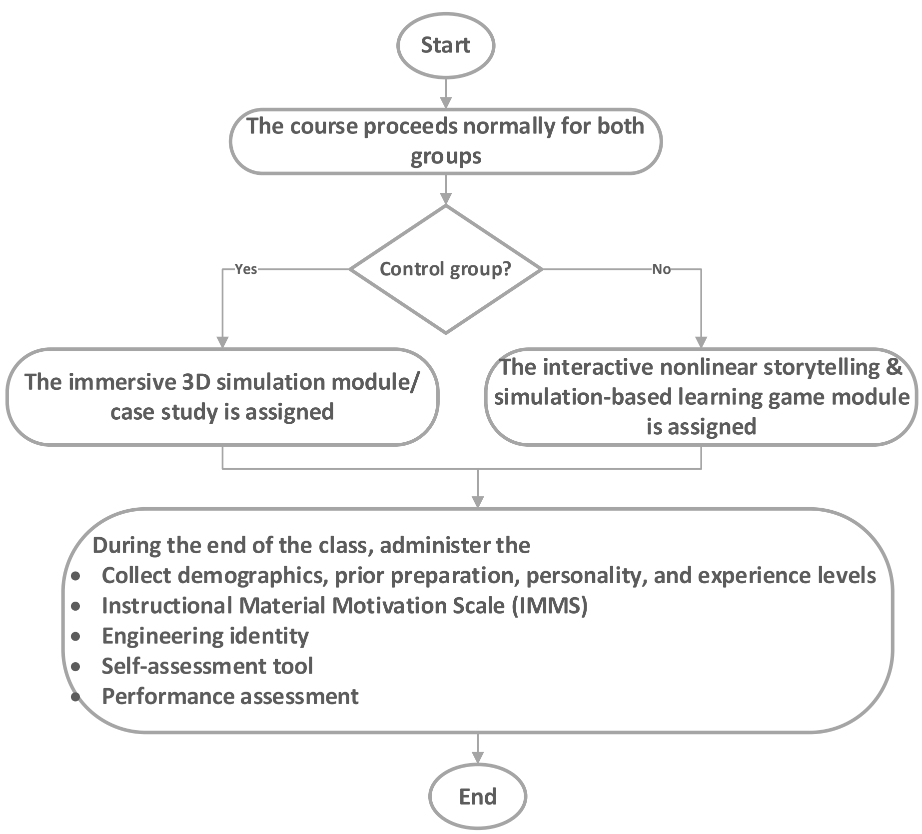

Figure 2. Experiment design and implementation

To test for groups homogeneity, Chi-squared tests were implemented and the results indicate that the proportion of participants with different gender identities, ethnicity, gaming experience level, VR experience level, and personality traits was not statistically significantly different between the groups (at an alpha level of 0.05). Moreover, the results of a t-test indicated that the mean GPA of the control group (M=2.96, SD=0.42) was not statistically significantly different than the mean GPA of the intervention group (M=3.21, SD=0.51), at an alpha level of 0.05. Thus, the participants in the control and intervention groups, on average, were not significantly different based on these measurements.

Table 2. Summary statistics of the demographics, experience, and personality

	Total		Control		Intervention	
	Freq.	*Prop.*	*Freq.*	*Prop.*	*Freq.*	*Prop.*
Gender Identity						
Female	13	0.30	9	0.45	4	0.22
Male	25	0.57	11	0.55	14	0.78
Other	0	0.00	0	0.00	0	0.00
Ethnicity						
Caucasian	28	0.64	15	0.75	13	0.72
Hispanic	2	0.05	1	0.05	1	0.06
Asian or Pacific Islander	6	0.14	3	0.15	3	0.17
African American	0	0.00	0	0.00	0	0.00
Other	2	0.05	1	0.05	1	0.06
Gaming Experience						
None	1	0.02	1	0.05	0	0.00
Some	16	0.36	8	0.40	8	0.44
Expert	21	0.48	11	0.55	10	0.56
VR Experience						
None	11	0.25	8	0.40	3	0.17
Some	27	0.61	12	0.60	15	0.83
Expert	0	0.00	0	0.00	0	0.00
Big-5 Personality Trait						
Extraversion	8	0.18	5	0.25	3	0.17
Agreeableness	14	0.32	6	0.30	8	0.44
Conscientiousness	8	0.18	6	0.30	2	0.11
Neuroticism	3	0.07	2	0.10	1	0.06
Openness	5	0.11	1	0.05	4	0.22

3.3.3 Results and Discussions

Table 3 shows the summary statistics of the Instructional Material Motivation Scale (IMMS), System Usability Scale (SUS), and the Engineering Identity questionnaire, as well as the performance assessment and the knowledge self-assessment based on Bloom's revised taxonomy, is presented in the experimental procedure shown in Figure 2.

Table 3. Statistical analysis summary of the dependent variables

	Control			Intervention			
	M	*Mdn*	*SD*	*M*	*Mdn*	*SD*	†
IMMS[1]							
Attention	9.9	10.5	3.29	12.61	13	1.85	**
Relevance	10.65	11.5	2.64	12.28	13	1.93	*
Confidence	12	13	2.51	12.94	13	1.3	-
Satisfaction	8.95	9	2.91	11.5	11	1.65	**
Overall=	41.5	43.5	10.6	49.33	50	3.83	**
SUS[2]							
Overall=	52.12	52.5	20.2	66.53	66	9.74	*
Engineering Identity[3]							
Recognition	15.85	16	1.76	13.78	14	1.98	**
Interest	15.6	16	4.49	14.06	14	2.55	*
Performance	23.9	25	4.47	22.67	22	2.74	-
Overall=	55.35	55	7.49	50.5	49	5.31	*
Self-assessemnt[4]							
Data Collection	4.65	5	1.49	4.83	5	1.25	-
Queueing Theory	4	4	1.37	3.88	4	1.18	-
Inventory Theory	4.41	4	1.37	4.5	5.99	1.46	-
Product Flow	4.11	4	1.32	4.33	5	1.18	-
Overall=	17.18	18	4.14	17.56	18	3.45	-
Performance Assessment							
Overall=	81.7	82	9.66	89.07	91.4	8.39	*

† Statistical significance (p-value) code: * <0.05, ** <0.005

[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) [25].

[2] The System Usability Scale (SUS) questionnaire requires users to rate a set of 10 statements using a 5 point-Likert scale [27]. 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) [24].

[4] The groups completed a self-assessment instrument after submitting the assignment. The instrument was based on Bloom's revised taxonomy [26] and it allows the students to rate their knowledge on six levels (level 6 is the highest). Figure 3 shows the self-assessment instrument with the concepts.

Instructional Materials Motivation Scale and System Usability Scale

When looking at the Instructional Materials Motivation Scale (IMMS) responses, the results of a series of non-parametric Mann-Whitney tests indicate that there were some statistically significant differences between the group. Specifically, participants in the intervention group reported higher levels in the constructs of Attention, Relevance, and Satisfaction, as well as in their overall IMMS score. Similarly, the results of a Man-Whitney test indicate that the intervention group reported greater system usability than the control group. These results indicate that the nonlinear story and simulation-based learning groups reported greater IMMS and SUS scores compared to the control group. These results indicate that the nonlinear story and simulation-based learning game might have been better perceived by the students than just the simulation-based learning environment alone, both in terms of motivation and usability. These results might support the value of adding the game elements including the nonlinear storytelling narrative, hints, score system, and choice, along with 3D simulation models. It should be noted that the students in this course never had any exposure to the simulation software (Simio®) before, so the results might also indicate that the addition of the game elements helped students' adoption of the simulation software.

Engineering Identity

Moreover, the results indicate that the control group reported statistically significantly greater Engineering Identify than the intervention group; particularly, in the constructs of Recognition and Interest. This indicates that the addition of the nonlinear story might have negatively impacted students' Engineering Identity. It was hypothesized that the intervention group would have reported a larger increase in Engineering Identity due to the addition of the game elements, i.e., story narrative and nonlinear choice, that tried to engage the students and contextualize the work of an industrial engineer working in a manufacturing facility. However, an opposite effect was seen, which might be due to the other game elements, such as the scoring system, that didn't help students identify with real-world engineering. It could be hypothesized that the addition of the game elements especially the story narrative and nonlinear choice might have made some students realize (Recognition) the reality of an engineering job in the workplace as well as question their interest (Interest) which in turn resulted in lowering the rating of their engineering identity. There was no statistically significant difference between the groups in terms of the third construct (Performance). More data and future research are needed to investigate the cause(s) of this phenomenon.

For every topic / method in each column, evaluate the level that best describes your knowledge of the concepts related to that topic / method.

	Topic / Method			
	Data Collection and Analysis	Queueing Models	Inventory Optimization	Product Flow Improvement
Level 1: I can remember related concepts/steps	○	○	○	○
Level 2: I can explain related concepts/steps	○	○	○	○
Level 3: I can apply this topic/method to a different problem/situation	○	○	○	○
Level 4: I can analyze the meaning of the related concepts/steps in the context and why they are there	○	○	○	○
Level 5: I can evaluate and ensure the correctness of use of the related concepts/steps	○	○	○	○
Level 6: I can use this topic/method in problem solving without an example	○	○	○	○

Figure 3. Self-assessment Bloom's revised taxonomy instrument

Performance Assessment and Self-assessment using Bloom's Revised Taxonomy

Both control and intervention groups also completed a self-assessment instrument after submitting the assignment. The instrument is based on Bloom's revised taxonomy and it allows the students to rate their knowledge on six levels (level 6 is the highest). Figure 3 shows the self-assessment instrument with the concepts. Similarly, the assignments for both groups were graded using the same rubric created by the course instructor. The results show that the intervention group, on average, performed better than the control group. However, there was no statistically significant difference in their self-assessment scores. In addition, while the results show that the performance of students in the control group was positively correlated with their reported self-assessment ($\rho=0.55$, p-value<0.05), this was not the case for the intervention group. This indicates that the control group was able to correctly assess their knowledge and understanding of the concepts covered in the assignment, but this was something the student in the intervention group were not able to achieve. The performance of students in the control group was also positively correlated with their IMMS responses ($\rho=0.59$, p-value<0.05) and their Engineering Identity responses ($\rho=0.62$, p-value<0.05); however, this correlation were not significant in the intervention group.

4. Conclusions and Future Works

This paper investigates the effectiveness of combining nonlinear storytelling and 3D simulation-based learning games on students' motivation, engineering identity, and learning outcomes. The study took place in the second course of operations research in the industrial engineering curriculum at Penn State University, The Behrend College. Two groups are used in this study. Both groups are taught the same material and instructed by the same instructor. The control group is exposed to a traditional case study that involves simulation models. On the other hand, the intervention group is exposed to the same case study but using a different delivery method, i.e., nonlinear storytelling and 3D simulation-based learning game module.

The results of the study show greater motivation and higher performance for the intervention group in comparison to the control group. Specifically, the Attention, Satisfaction, and Relevance of the ARCS model are statistically significantly different between the groups. In addition, the overall motivation score is higher for the intervention group. Looking at the usability score, the nonlinear storytelling and 3D simulation-based learning scored higher in comparison to the use of traditional case studies and simulation-based learning.

Concerning the engineering identity, the control group reported statistically significantly higher scores for the Recognition and Interest constructs of the engineering identity while the groups were not different for the Performance construct. These results were not expected as it was hypothesized that the game learning module will improve the students' engineering identity. The authors think that the addition of the game elements (i.e., story narrative and nonlinear choice) might have made some students realize (Recognition) the reality of an engineering job in the workplace as well as question their interest (Interest) which in turn resulted in lowering the rating of their engineering identity. Future work should focus on investigating this phenomenon.

Furthermore, other students' characteristics such as experiences with games should be investigated for possible correlation with this phenomenon.

The learning outcomes were measured by the self-assessment and students' grades. The intervention group showed higher performance in comparison to the control group. However, the difference between the groups in the self-assessment score was not statistically significant.

This study has resulted in useful and interesting conclusions. However, some limitations are worth mentioning. The validity of the conclusions can be enhanced by increasing the experiment sample size. Moreover, the delivery mode of the course that was taught to the control group (Fall 2020) was remote synchronous due to the COVID-19 pandemic. On the other hand, the intervention group was taught in person. As a consequence, different delivery modes could have influenced the results (positively or negatively) but that was not accounted for in this experiment.

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References

[1] A. A. Deshpande and S. H. Huang, "Simulation games in engineering education: A state-of-the-art review," *Comput. Appl. Eng. Educ.*, vol. 19, no. 3, pp. 399–410, 2011, doi: 10.1002/cae.20323.

[2] M. Letonsaari, L. Karjalainen, and J. Selin, "Nonlinear Storytelling Method and Tools for Low-Threshold Game Development," *Semin. - Int. J. media, Technol. lifelong Learn.*, vol. 15, no. 1, pp. 1–17, 2019.

[3] E. R. Wester, L. L. Walsh, S. Arango-Caro, and K. L. Callis-Duehl, "Student Engagement Declines in STEM Undergraduates during COVID-19–Driven Remote Learning," *J. Microbiol. Biol. Educ.*, vol. 22, no. 1, 2021, doi: 10.1128/jmbe.v22i1.2385.

[4] Simio.com, "SImulation Modeling framework based on Intelligent Objects." https://www.simio.com/.

[5] C. Klimas, "Twine." https://twinery.org/.

[6] J. Lave and E. Wenger, *Situated learning: Legitimate peripheral participation*. Cambridge, MA: Cambridge University Press, 1991.

[7] R. E. Mayer, "Problem Solving," in *The Oxford Handbook of Cognitive Psychology*, D. Reisberg, Ed. New York: Oxford University Press, 2013, pp. 769–778.

[8] D. Shaffer, Kurt S, R. Halverson, and J. Gee, "Video Games and The Future of Learning," *Phi delta kappan*, vol. 87, no. 2, pp. 105–111, 2005, [Online]. Available: http://blog.lib.umn.edu/swiss/archive/videogames.doc.

[9] K. Squire, "From Content to Context: Videogames as Designed Experience," *Educ. Res.*,

vol. 35, no. 8, pp. 19–29, 2006, doi: 10.3102/0013189X035008019.

[10] N. Campos, M. Nogal, C. Caliz, and A. A. Juan, “Simulation-based education involving online and on-campus models in different European universities,” *Int. J. Educ. Technol. High. Educ.*, vol. 17, no. 1, 2020, doi: 10.1186/s41239-020-0181-y.

[11] C. E. Lopez, O. Ashour, and C. Tucker, “An introduction to the CLICK approach: Leveraging virtual reality to integrate the industrial engineering curriculum,” 2019.

[12] O. Ashour, C. E. Lopez, J. Cunningham, and C. S. Tucker, “Connected Learning and Integrated Course Knowledge (CLICK) Approach Connected Learning and Integrated Course Knowledge (CLICK) Approach,” 2021.

[13] C. E. Lopez, J. Cunningham, O. Ashour, and C. S. Tucker, “Deep Reinforcement Learning for Procedural Content Generation of 3D Virtual Environments,” *J. Comput. Inf. Sci. Eng.*, vol. 20, no. October, pp. 1–33, 2020, doi: 10.1115/1.4046293.

[14] C. E. Lopez, O. Ashour, J. Cunningham, and C. Tucker, “The CLICK Approach and its Impact on Learning Introductory Probability Concepts in an Industrial Engineering Course,” 2020.

[15] C. E. Lopez, O. M. Ashour, J. Cunningham, and C. S. Tucker., “A Study on the Effectiveness of the CLICK Approach in an Operations Research Course,” *ASEE Annu. Conf. Expo.*, 2021.

[16] J. Cunningham, C. Lopez, O. Ashour, and C. S. Tucker, “Multi-Context Generation in Virtual Reality Environments using Deep Reinforcement Learning,” in *Proceedings of the ASME 2020 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE)*, 2020, pp. 1–11.

[17] S. G. Ozden, O. M. Ashour, and A. Negahban, “Novel Simulation-Based Learning Modules for Teaching Database Concepts,” *ASEE Annu. Conf. 2020*, 2020, [Online]. Available: https://www.gokhanozden.com/wp-content/uploads/2020/04/Novel-Simulation-Based-Learning-Modules-for-Teaching-Database-Concepts.pdf.

[18] C. E. Lopez, O. Ashour, and C. S. Tucker, “Reinforcement learning content generation for virtual reality applications,” *Proc. ASME Des. Eng. Tech. Conf.*, vol. 1, pp. 1–11, 2019, doi: 10.1115/DETC2019-97711.

[19] J. M. Koivisto, H. Niemi, J. Multisilta, and E. Eriksson, “Nursing students’ experiential learning processes using an online 3D simulation game,” *Educ. Inf. Technol.*, vol. 22, no. 1, pp. 383–398, 2017, doi: 10.1007/s10639-015-9453-x.

[20] R. Kleinert, R. Wahba, D. H. Chang, P. Plum, A. H. Hölscher, and D. L. Stippel, “3D immersive patient simulators and their impact on learning success: A thematic review,” *J. Med. Internet Res.*, vol. 17, no. 4, p. e91, 2015, doi: 10.2196/jmir.3492.

[21] A. A. Tawfik, M. M. Schmidt, and F. Msilu, “Stories as Decision Scaffolds: Understanding Nonlinear Storytelling Using Case-Based Reasoning and Educational Design Research,” *Educ. Technol. Narrat.*, pp. 21–38, 2018, doi: 10.1007/978-3-319-69914-1_3.

[22] A. Maleki and S. Sajjadi, “The Role of Non-linear Methods in Teaching English for Medicine: Example of Storytelling,” *J. Appl. Sci.*, vol. 12, no. 18, pp. 1972–1977, 2012.

[23] B. Rammstedt and O. P. John, “Measuring personality in one minute or less: A 10-item short version of the Big Five Inventory in English and German,” *J. Res. Pers.*, vol. 41, no. 1, pp. 203–212, 2007, doi: 10.1016/j.jrp.2006.02.001.

[24] A. Godwin, “The Development of a Measure of Engineering Identity,” in *Annual Conference of the American Society for Engineering Education (ASEE)*, 2016, p. 14814.

[25] N. Loorbach, O. Peters, J. Karreman, and M. Steehouder, “Validation of the Instructional Materials Motivation Survey (IMMS) in a self-directed instructional setting aimed at working with technology,” *Br. J. Educ. Technol.*, vol. 46, no. 1, pp. 204–218, 2015, doi: 10.1111/bjet.12138.

[26] S. Alaoutinen and K. Smolander, “Student self-assessment in a programming course using Bloom’s Revised Taxonomy,” *ITiCSE’10 - Proc. 2010 ACM SIGCSE Annu. Conf. Innov. Technol. Comput. Sci. Educ.*, pp. 155–159, 2010, doi: 10.1145/1822090.1822135.

[27] J. Brooke, “SUS: A Retrospective,” *J. Usability Stud.*, vol. 8, no. 2, pp. 29–80, 2013, doi: 10.1016/j.eururo.2011.07.008.