An Assessment of Simulation-Based Learning Modules in an Undergraduate Engineering Economy Course

Abstract

We propose and assess the effectiveness of novel immersive simulation-based learning (ISBL) modules for teaching and learning engineering economy concepts. The proposed intervention involves technology-enhanced problem-based learning where the problem context is represented via a three-dimensional (3D), animated discrete-event simulation model that resembles a real-world system or situation that students may encounter in future professional settings. Students can navigate the simulated environment in both low- and high-immersion modes (i.e., on a typical personal computer or via a virtual reality headset). The simulation helps contextualize and visualize the problem setting, allowing students to observe and understand the underlying dynamics, collect relevant data/information, evaluate the effect of changes on the system, and learn by doing. The proposed ISBL approach is supported by multiple pedagogical and psychological theories, namely the information processing approach to learning theory, constructivism theory, self-determination theory, and adult learning theory. We design and implement a set of ISBL modules in an introductory undergraduate engineering economy class. The research experiments involve two groups of students: a control group and an intervention group. Students in the control group complete a set of traditional assignments, while the intervention group uses ISBL modules. We use well-established survey instruments to collect data on demographics, prior preparation, motivation, experiential learning, engineering identity, and self-assessment of learning objectives based on Bloom's taxonomy. Statistical analysis of the results suggests that ISBL enhances certain dimensions related to motivation and experiential learning, namely relevance, confidence, and utility. We also provide a qualitative assessment of the proposed intervention based on detailed, one-on-one user testing and evaluation interviews.

Introduction and Background

The Immersive Simulation-Based Learning (ISBL) approach proposed in this paper aims to close the gap between learning and skills that the students attain during their education and the real-life problems they face and solve in their professional life. ISBL offers an alternative teaching and learning method that combines the benefits of immersive simulated environments and problem-based learning (PBL). ISBL is student-centered and aims to motivate students to formulate engineering problems and situations based on real-life context. This paper focuses on an implementation and assessment of ISBL for teaching and learning engineering economy. The interested reader is referred to [1] for another application of ISBL in a database design course.

Engineering economy is one of the fundamental courses in an engineering curriculum and one of the core engineering competencies covered in the Fundamentals in Engineering (FE) exam. The concepts learned in an engineering economy course aim to help engineers make informed and economical decisions in engineering settings [2]–[5]. The topics covered are useful to the students in their personal and professional life, providing many opportunities to incorporate real-life examples to enhance teaching and learning. Nevertheless, engineering economy is generally characterized as a course with a high failure rate, which is often attributed to engineering students' low engagement and motivation toward the topics covered in the course [6]. In addition, students usually struggle to apply what they have learned in class in actual engineering applications [6]. Through the proposed ISBL approach, we aim to improve students' motivation and engagement by providing a contextualized learning experience designed to enhance problem-solving skills.

PBL is a well-known student-centered approach that utilizes active learning where students solve complex problems that mimic problems encountered in real-life applications [7]. PBL has proved to improve innovation [8], metacognition [9], engagement and meaningfulness [10], [11]. In addition, it encourages design thinking [12] as well as curriculum integration [13], [14]. PBL helps students learn by applying the learned knowledge rather than memorizing it [15] and is recommended as an effective teaching and learning method in engineering economy courses [16].

On the other hand, simulated and immersive environments, such as virtual reality (VR), insert the user into a virtual world with which the user can interact [17]. Several studies have investigated the effectiveness of immersive technologies in engineering education [18]. Immersive technologies provide portable and risk-free learning environments that facilitate location-independent learning [18]. Moreover, these technologies are shown to enhance certain learning outcomes in engineering disciplines such as creativity and spatial skills [18]. The reader is referred to [19] for a comprehensive review of immersive virtual environments in higher education, and to [20] for a bibliometric analysis on the combination of PBL and immersive technologies in engineering education.

In this paper, we propose and investigate the effectiveness of ISBL as an alternative teaching and learning method that enables PBL in the context of an immersive simulated environment. In the following sections, we first describe the different components of ISBL, supporting pedagogical and psychological theories, as well as the sample ISBL modules used in our experiments related to an undergraduate engineering economy course. We then describe the experimental design and present the results of our quantitative assessments and statistical comparisons as well as a set of qualitative assessments based on user interviews. Finally, we will conclude the paper by discussing the lessons learned and future research opportunities.

Immersive Simulation-Based Learning (ISBL)

The proposed ISBL modules are specified by:

a) A *three-dimensional, VR-compatible discrete-event simulation model* that resembles a real system or environment. The simulation serves as the context and enables technology-enhanced PBL. The simulation models used in the proposed ISBL modules can be explored in 2D on any typical display or via a VR headset for an enhanced immersive experience.

b) A set of *entities* in the simulation that can represent people, products, raw material, information/data that are processed, assembled, manufactured, stored, transferred, or transported depending on the context being simulated.
c) A set of *processes* in the simulated environment that represent the stages or stations that the entities go through during the simulation run.
d) A *learning activity* in the form of problem- or project-based learning defined around the simulated system. The learning activity is inspired by and resembles real-world situations that learners may face in a professional setting or future workplace.

Many of the pedagogical and psychological theories that support PBL also apply to ISBL or are augmented as a result of the integration with a virtual/simulated environment. For example:

- ISBL enables long-lasting development of critical thinking and problem-solving skills by: (a) activating relevant prior knowledge; (b) providing a contextually enriched environment (via immersive simulations) that mimics future professional settings; and, (c) encouraging learners to elaborate on their knowledge to solve a real-world inspired problem. These are the three principles of the *Information Processing Approach to Learning* theory [21].
- The immersive simulations in ISBL provide the context and an environment to interact with, which are often missing in STEM education. By doing so, ISBL enables knowledge to be constructed via interactions with the virtual environment and indexed by relevant contexts. This aligns with the *Constructivism Theory* [22], which suggests learners construct their interpretations of the real-world world through cognitive and interpretive activities and help construct mental models by accommodating new ideas/phenomena with prior knowledge.
- ISBL enables learners to incorporate their views and take greater responsibility for their learning. As a result, ISBL aligns with the *Self-determination Theory* [23] by promoting *autonomous* motivators, unlike traditional methods that are primarily based on *controlled* motivators such as rewards and punishments (e.g., passing or failing a test), which often lead to superficial learning and cause a sense of pressure and anxiety.
- ISBL is also suitable for professional and continuing education as it supports some of the main pillars of the *Adult Learning Theory* [24] by providing a self-directed and problem-centered learning experience that draws on previous work experiences and integrates into the professional learner's everyday life as ISBL problems/projects resemble real-world situation.

For the ISBL modules investigated in this paper, the immersive simulations are developed using the Simio® simulation software [25], which does not incur any technology fee for academic and classroom use and is compatible with VR, giving the learner the option to view the simulated environment on a 2D display (low-immersion mode) or via a VR headset (high-immersion mode). Students use virtual site visits (by navigating in the simulation) to make observations and collect any necessary data (as opposed to visiting a real-world facility in person). This helps eliminate several critical barriers in current STEM education and workforce development, namely: (a) geographical barriers that prohibit contextualized learning, e.g., lack of proximity to industries or geographically dispersed formal/informal learners in online education; (b) companies' reluctance to provide access to their facilities and data; and/or, (c) logistics/schedule constraints that prohibit real-world site visits (e.g., conflict with other classes or work commitments for professional students).

The following section describes the integration of several ISBL modules in an undergraduate engineering economy class that we used in our assessment experiments. For a list of ISBL modules developed for other STEM courses/disciplines, please see our project website at https://sites.psu.edu/immersivesimulationpbl.

ISBL Implementation in an Undergraduate Engineering Economy Course

The Industrial Engineering (IE) Department at Penn State University - The Behrend college offers an undergraduate introductory course in engineering economy. This is a required course for IE students and an elective course for other engineering and engineering technology majors. The course is offered in the fall and spring semesters. The high-level objectives of the course can be summarized as follows:

- Apply the theoretical and conceptual basics of financial analysis including time-value of money, cash flow diagrams, economic equivalence, present worth analysis, annual worth analysis, cost-benefit analysis, rate-of-return, depreciation, and income taxes.
- Make informed financial decisions when selecting among several investment options.
- Identify how engineering decisions during product design, process selection, manufacturing system design, etc. can affect a company's financial performance.
- Develop skills that extend the basic concepts needed to solve various problems encountered in professional and personal financial situations.

The class is structured to be taught online and includes video lectures, online assessment questions for each lecture, quizzes, homework assignments, and three exams. The course sections used in this study were offered in Fall 2020 and Spring 2021. Our experiment (as described in the following section) involved a “control” and an “intervention” group. Both groups used the same material offered by the same instructor and via the same delivery method. The only difference was the use of the ISBL learning module instead of traditional homework assignments for the intervention group.

Four ISBL modules are integrated into the course to mimic real-life systems and engineering economy problems. Students are given a week to complete each ISBL assignment following the lecture on the respective topic. The document that comes with each module includes a description of the system at hand and the engineering economy problem(s) to be solved. In each ISBL module, the students are given a role. For example, in one of the modules the student is “hired” as a consultant to help a restaurant compare different loan options and select the most economical alternative. Each module is also accompanied by a 3D, VR-compatible, animated simulation model that is to be treated as the “real-world system” under study. The ISBL modules used in our experiments are related to a restaurant, a manufacturing assembly plant, a warehouse, and an airport terminal. Figure 1 provides a screenshot of some of the simulated systems used in the ISBL modules.

Figure 1. The simulation environments associated with the ISBL modules used in this paper.

For the sake of conciseness, we describe only one of the ISBL modules here and refer the interested reader to our project website at https://sites.psu.edu/immersivesimulationpbl where all ISBL modules developed as part of our ongoing project are shared publicly. The airport terminal has two areas with several self-check-in kiosks, a check-in counter, one ID/boarding pass check-point station, and two advanced imaging technology (AIT) stations for scanning passengers and their luggage. There are two gates in the boarding area at the terminal each having its own seating/waiting area, where passengers wait before boarding on their flight. Flights board and leave according to a stochastic process specified in the simulation model.

The engineering problem to be solved is as follows. The airport terminal plans to purchase and install vending machines near the gates to serve the passengers. Six candidate options have been identified that vary in terms of the number and type of vending machines to be installed, the number of choices (menu items), price, and quality of the drinks/snacks. Students are asked to treat the simulation as the "real" system and use virtual site visits to collect the data that they need to perform an economic analysis.

As for the learning objectives, after successful completion of the ISBL module, the student will be able to:

1. Collect data from the real-world system under study and estimate the cash flows needed for the economic analysis.
2. Compute the internal rate of return (IRR) for the investment options under consideration.
3. Perform rate of return (ROR) analysis to compare multiple alternatives and select the most economical option.
4. Perform present worth (PW) analysis to compare multiple alternatives and select the most economical option.
5. Verify the ROR and PW analyses by comparing the outcomes of the two methods.

Research and Experiment Design

Our study compares two groups of students: an "intervention" group that used ISBL modules as part of their assignments; and a "control" group that used traditional textbook problems as assignments. All other factors including the instructor, course syllabus/structure, instructional mode, textbook, etc. remain the same for both groups. Figure 2 summarizes the experiment process.

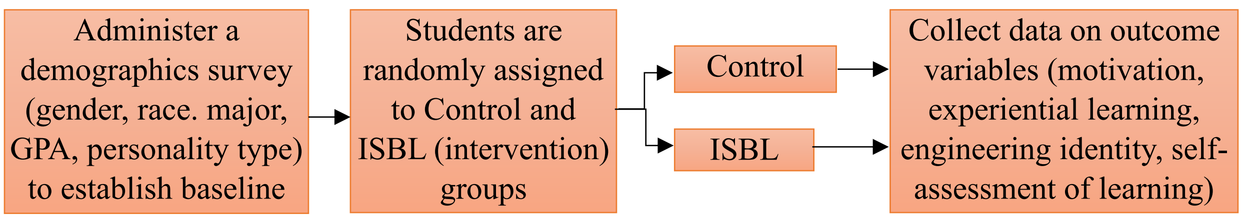

Figure 2. General design of the assessment experiments

We use the following instruments to collect data from research participants (all necessary IRB approvals are obtained prior to the experiment and data collection).

1. **Demographics survey:** The survey is used to collect data on gender, race, grade point average (GPA), major, semester standing, prior work experience, and personality type.
2. **Big Five Inventory (BFI-10) personality test:** The BFI survey questionnaire collects data about students' behavioral personalities and behavior across various situations [26]. The 10-item BFI measurement is developed to allow effective assessment of the five personality dimensions including Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness.
3. **Instructional Materials Motivation Scale (IMMS):** The IMMS survey is used to assess the student's motivation. The survey consists of 12 Likert scale questions measuring attention, relevance, confidence, and satisfaction for those earning an engineering degree.
4. **Experiential Learning Survey:** Experiential or experience-based learning generally refers to settings where students participate in activities that enable learning by doing. This instrument is a 12-item questionnaire that evaluates the student's perception of experience-based educational instruction as established in the experiential learning theory

[27]. Here, we specifically focus on two of the constructs measured by this instrument, namely how the *environment* influenced learning, and how useful the learning experience was in terms of potential *utility* in future endeavors. It is worth noting that the original experiential learning instrument includes two other constructs, namely *active learning* and *relevance*, which were excluded in our implementation of this instrument due to their overlap with the constructs measured by the other instruments that we used here. For example, *relevance* is measured by the IMMS survey, and *active learning*, which refers to the student's level of engagement with the learning material, is directly related to "Attention" – also measured by IMMS.

5. **Engineering Identity Survey**: The engineering identity survey is created to understand students' career choices and interests in engineering fields [28]. The 10-item questionnaire is constructed to measure three constructs related to the student's: (a) perception of their performance and competency, i.e., ability to perform well in gaining engineering knowledge; (b) interest in the (engineering) subject; and (c) recognition, i.e., being acknowledged by their peers/instructors as a successful engineering student.
6. **Self-assessment based on Bloom's Taxonomy of learning objectives:** This self-assessment survey is designed to provide insights into students' self-perceived knowledge related to a set of topics/concepts [29]. In our study, students are asked to rank their knowledge of various engineering economy topics by selecting one of six levels adapted from Bloom's taxonomy that they think best describes their level of learning. For each topic, the six levels that the respondent can choose from are as follows: (1) I can *remember* related concepts/methods; (2) I can *explain* related concepts/methods; (3) I can *apply* this topic/method to a different problem/situation; (4) I can *analyze* the meaning of and justification for related concepts/methods; (5) I can *evaluate* and ensure the correct use of the related concepts/methods; (6) I can *create* new solutions by using this topic/method in other problem-solving situations without an example.
7. **Student interviews:** Interviews are conducted with student volunteers from the class to obtain a qualitative assessment of their experience with the ISBL modules. Interviews are influenced by ethnographic methods and followed six structured questions designed to fit into a twenty-minute interview format [30]. Questions covered what students like best about the ISBL modules, suggestions for improvement, navigation experience, impact on learning, recommendations for future users, and an "Anything else to add" question. Interview notes were taken and analyzed using qualitative data analysis techniques from Grounded Theory to produce a set of themes across student experiences [31].

Student Population

We use the demographics and BFI personality surveys to establish a baseline and ensure that the two groups are comparable. Table 1 shows the gender composition of the students in the control and ISBL group. As shown in Figure 3(a), most students in both groups are from engineering majors, but the ISBL group has a higher percentage of non-engineering majors (8.2%) compared to 3.1% in the control group (this has important implications for the results related to engineering identity as discussed later). As shown in Figure 3(b), most students in both groups are seniors.

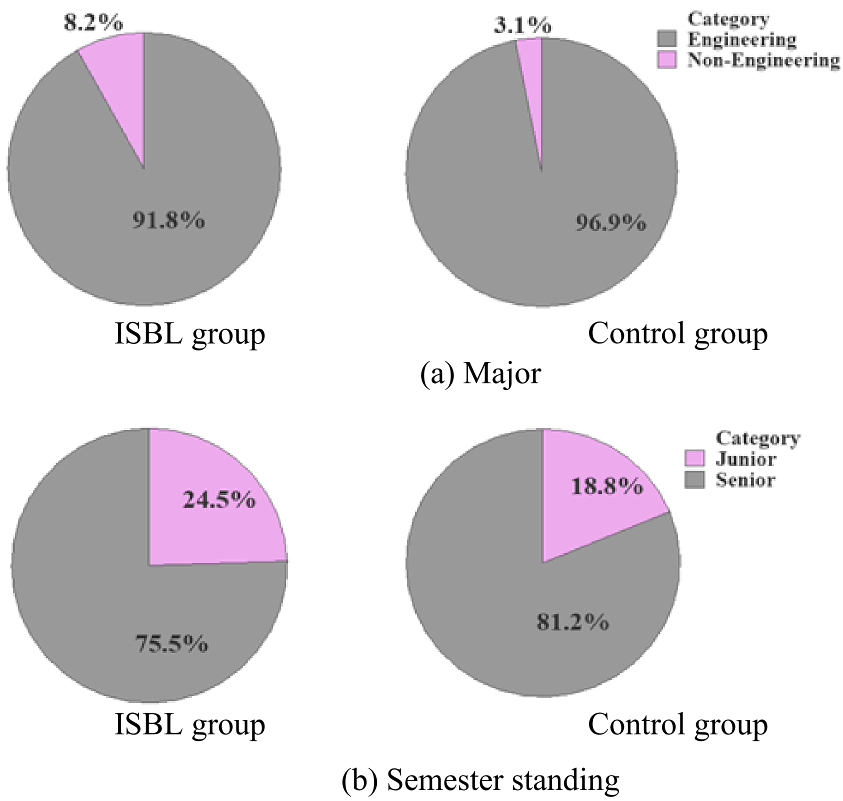

Figure 3. Group composition based on major and semester standing

Table 1. Gender composition of the two groups

	Female	Male	Other
Control group	9.1%	90.9%	0%
ISBL group	17.6%	82.4%	0%

Table 2 shows the mean, median, and standard deviation of the five BFI personality dimensions for the two groups. Our two-sample t-tests indicate no statistical differences between the two groups related to these dimensions at a 5% level of significance. As shown in Table 3, a two-sample t-test at a 5% significance level indicates no significant statistical difference between the two groups in terms of the average GPA (i.e., we fail to reject $H_0: \mu_{GPA}^{Control} - \mu_{GPA}^{ISBL} = 0$). Figure 4 shows that the GPA distribution is also similar for the two groups of students being compared.

Table 2. BFI personality test results for the two groups

BFI dimension	Control			ISBL			Test outcome
	Mean	Median	Stdev	Mean	Median	Stdev	p-value
Extroversion	5.636	5	1.782	6.118	6	1.740	0.227
Agreeableness	4.788	4	2.073	4.804	5	1.442	0.969
Conscientiousness	3.82	3	1.67	4.12	4	1.35	0.391
Neuroticism	6.515	6	2.167	6.275	6	1.877	0.603
Openness	4.909	5	1.156	4.980	5	1.407	0.801
Overall	25.668	23	8.848	26.297	26	7.816	2.991

Table 3. GPA comparison between the two groups

	Control			ISBL			Test outcome
	Mean	Median	Stdev	Mean	Median	Stdev	p-value
GPA	3.111	3.20	0.531	2.917	2.85	0.623	0.132

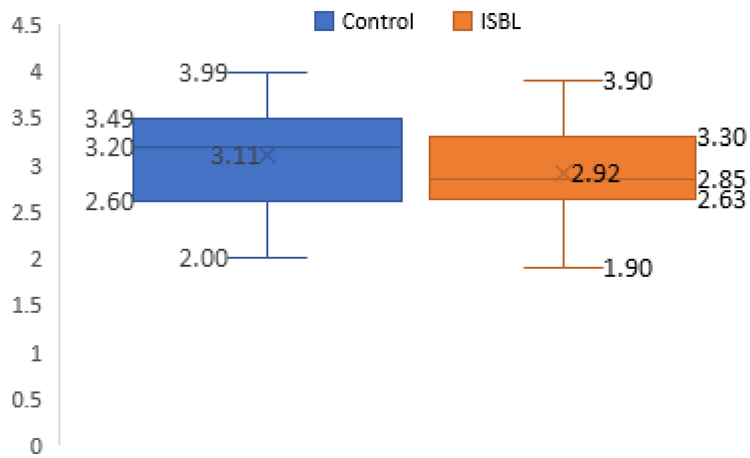

Figure 4. GPA distribution comparison

Research Hypotheses

Based on the above results, it would be reasonable to assume that the two groups are comparable in terms of academic and personality factors and that any statistical difference observed between the two groups regarding the outcome variables can be attributed to the intervention implemented, i.e., the ISBL modules. More specifically, our experiment aims to investigate the following hypotheses:

1. The ISBL group shows higher motivation than the control group as measured by the IMMS instrument.
2. The ISBL group shows higher levels of experiential learning than the control group as measured by the experiential learning survey.
3. The ISBL group shows higher engineering identity than the control group as measured by the engineering identity instrument.
4. Students in the ISBL group perceive higher levels of learning as measured by the self-assessment questionnaire based on Bloom's taxonomy of learning objectives.

Quantitative Assessments: Statistical Comparisons and Results

All statistical tests presented in this section are performed at a 5% level of significance. As for the first research hypothesis, Table 4 shows the mean, median, and standard deviation of the four dimensions related to motivation as measured by the IMMS instrument for the control and ISBL group. The ISBL group shows a higher mean and median for all IMMS constructs compared to the control group. Especially, our two-sample t-tests indicate a *highly* statistically significant improvement for "Confidence". For "Relevance", we barely fail to reject the null hypothesis with a p-value of 0.051, just over the cut-off point of 0.05, deserving of further investigation with additional data. The improvement in motivation can be explained by noting that ISBL is inspired by and resembles real-world situations that the learner may encounter at the future workplace, hence students see higher relevance and report a more positive attitude towards success as they feel more confident about their ability to handle real-world problems.

Table 4. Motivation comparisons (H_0: $\mu_{RIMMS}^{Control} - \mu_{RIMMS}^{ISBL} = 0$)

IMMS dimension	Control			ISBL			Test outcome
	Mean	Median	Stdev	Mean	Median	Stdev	p-value
Attention	8.588	8	2.851	9.633	10	3.264	0.126
Relevance	7.059	7	2.51	8.265	8	3.012	0.051
Confidence	6.618	6	2.57	9.286	9	3.075	**0.000****
Satisfaction	9.824	10	3.406	10.83	11	3.406	0.158
Overall	32.9	31	11.337	38.02	38	12.75	0.335

As for the second research hypothesis, Table 5 shows the mean, median, and standard deviation of the two constructs investigated via the experiential learning instrument, namely "Environment" and "Utility". According to the test results, the ISBL group shows a higher level with respect to "Utility" compared to the control group and that the observed difference is *highly* statistically significant. We believe this improvement is because ISBL resembles real-world inspired problems, allowing the students to more clearly see that what they learn is useful and applicable in real-world settings.

Table 5. Experiential learning comparisons (H_0: $\mu_{Experiential}^{Control} - \mu_{Experiential}^{ISBL} = 0$)

Experiential learning construct	Control			ISBL			Test outcome
	Mean	Median	Stdev	Mean	Median	Stdev	p-value
Environment	17.41	17.5	3.88	17.12	17.0	4.40	0.753
Utility	19.68	18	7.33	24.49	22	9.12	**0.009****
Overall	37.09	35.5	11.21	41.61	39	13.52	0.762

As for the third research hypothesis, Table 6 shows the mean, median, and standard deviation of the constructs related to engineering identity. We observe a statistical difference between the two groups for "Recognition"; however, this time the Control group seems to be performing better with respect to this construct. We believe that this finding is primarily due to two reasons: (a) the ISBL group has a higher percentage of non-engineering majors (8.2%) compared to the control group which has only 3.1% non-engineering students as shown in Figure ; hence it would be unreasonable to expect a statistically higher engineering identity for the ISBL group; and, (b) the scope and duration of our intervention is too limited/short to make a significant impact on the student's engineering identity (i.e., we implemented only a few ISBL modules in a single course). There is a need for a longitudinal study over an extended period and multiple courses to investigate the impact of ISBL on engineering identity.

Table 6. Engineering identity comparisons (H0 : $\mu_{Eng\ identity}^{Control} - \mu_{Eng\ identity}^{ISBL} = 0$)

Engineering identity construct	Control			ISBL			Test outcome
	Mean	Median	Stdev	Mean	Median	Stdev	p-value
Recognition	7.32	6.5	2.86	5.94	6.5	2.33	**0.023***
Interest	5.91	6	2.44	4.92	4	1.88	0.051
Performance	11.15	11	3.71	11.67	10	4.53	0.564
Overall	24.38	23.5	9.01	22.53	20.5	8.74	0.638

As for the fourth research hypothesis, Table 7 shows the mean, median, and standard deviation of the self-assessment results for the control and ISBL groups. Two sample t-tests are performed for every concept/topic related to the ISBL modules used. The results indicate no significant statistical difference between the two groups related to self-assessment, while both groups report the same median for all topics. In conclusion, the results show that the ISBL modules enhanced motivation and experiential learning without any adverse impact on students' self-perceived learning.

Table 7. Self-assessment results (H0: $\mu_{Self-assesment}^{Control} - \mu_{Self-assesment}^{ISBL} = 0$)

Concept/Topic	Control			ISBL			Test outcome
	Mean	Median	Stdev	Mean	Median	Stdev	p-value
Commercial loans	4.00	4	1.56	3.75	4	1.58	0.523
Effect of inflation	4.09	4	1.40	3.88	4	1.27	0.486
Annual worth analysis	3.82	4	1.66	4.12	4	1.44	0.398
Rate of return analysis	3.82	4	1.45	3.67	4	1.66	0.663
Overall	15.74	16	5.21	15.45	16	4.23	0.792

Qualitative Assessment

Qualitative interviews about the ISBL module experience were conducted with ten students in the fall of 2020 and the spring of 2021. Themes emerged from the data which support three of the four hypotheses and findings from the results of the quantitative analysis. The first theme for discussion is "Real World Context." For this theme, students discussed the applicability of the ISBL modules for their future careers. To this point, one student stated that the modules were a "nice representation of what you would actually do in the workplace." Similarly, another student said, "looking at real life situations helped understand the data collection." Students also recognized the real-world value of the simulations during the COVID-19 pandemic, as one student mentioned: "It was valuable to have this during a pandemic when we can't actually visit a site." This theme supports both the development of motivation found in the assessments of hypothesis 1 and the recognition of utility found in the assessment of hypothesis 2 as a result of operating in a more real-world context. As one student succinctly put it, you are "seeing the overall picture and not just focused on pizza slices."

A second theme related to “Engagement” emerged from the interview data. For this theme, students described the ISBL modules as “fun, like playing a game”, “better than a lecture for engagement,” and “made me look forward to using the assignments in class.” Another student summed this up as, “overall, a very interesting part of the course.” This theme supports hypothesis 1 related to motivation. In this interpretation, students become engaged in the modules, and this leads to the development of their confidence as the statistical test results also indicate.

A third theme that emerged related to “Learning about a Career.” In this theme, students described the impact of the ISBL modules on understanding potential career tracks after school. One student stated, “going to be a good experience if I get an internship, would help understand what it would be like to work in this field.” Another student stated that the modules were a “great indicator of what to expect when going into this type of work.” This theme provides some support for hypothesis 3 related to identity development. Although quantitative assessment results did not show a statistical improvement, these qualitative results show that students are learning about a possible career track and additional tracking of career identity over time might eventually lead to significant development in this area.

Conclusions

In this paper, we proposed and implemented ISBL for teaching and learning engineering economy. ISBL involves an immersive simulation that serves as the context for problem-/project-based learning. Students can make virtual site visits and interact with the simulation in desktop mode (low-immersion) or in VR mode (high-immersion). The statistical comparisons from a controlled experiment conducted in an undergraduate engineering economy course show that ISBL improves motivation and experiential learning. These findings are also manifested in the qualitative user interviews with a sample of research participants.

ISBL modules can be used as in-class examples during lectures, homework/exam problems, or an individual or group project. Implementing ISBL does not require any technology fee or access to special immersive technologies as the simulation software is free for academic use and the simulations can be used on any typical computer. In the implementations discussed in this paper, we replaced a set of traditional homework problems with related ISBL modules without restructuring or modifying other aspects of the course. In order to further facilitate ISBL adoption by other instructors and educational researchers, we publicly share a set of ISBL modules for various STEM topics on the website for our ongoing project available at https://sites.psu.edu/immersivesimulationpbl.

Our experiment results reveal two important areas for future extensions. First, a longitudinal study is needed to assess the effect of ISBL on engineering identity and its related constructs, as intervention in a single course is less likely to make a significant impact on students’ engineering identity. Secondly, additional experiments are needed to assess the impact of ISBL on learning. Our self-assessment survey failed to capture a statistical difference between the control and intervention groups, hence we would recommend use of alternative instruments to measure learning.

We hope that this paper and its extensions will encourage the use of immersive simulations in conjunction with PBL in engineering education.

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References

[1] S. G. Ozden, O. M. Ashour, and A. Negahban, "Novel simulation-based learning modules for teaching database concepts," *ASEE Annu. Conf. Expo. Conf. Proc.* 2020, doi: 10.18260/1-2--35001.

[2] D. Newnan, T. Eschenbach, J. Lavelle, and N. Lewis, *Engineering Economy Analysis*, 14th ed. New york: Oxford University, 2019.

[3] J. A. White, K. E. Case, and D. B. Pratt, *Principles of Engineering Economic Analysis*, 6th ed. Wiley, 2012.

[4] W. Sullivan, E. Wicks, and C. Koelling, *Engineering Economy*, 17th ed. Pearson, 2019.

[5] C. Park, *Fundamentals of Engineering Economics*, 4th ed. Pearson, 2019.

[6] A. Sarfaraz and T. Shraibati, "Increasing student engagement in engineering economy class," *ASEE Annu. Conf. Expo. Conf. Proc.*, 2006, doi: 10.18260/1-2--1249.

[7] "Problem-Based Learning | Center for Teaching Innovation." https://teaching.cornell.edu/teaching-resources/engaging-students/problem-based-learning (accessed Mar. 14, 2021).

[8] M. Lehmann, P. Christensen, X. Du, and M. Thrane, "Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education," *Eur. J. Eng. Educ.*,2008, vol. 33, no. 3, pp. 283–295, doi: 10.1080/03043790802088566.

[9] K. Downing, T. Kwong, S. W. Chan, T. F. Lam, and W. K. Downing, "Problem-based learning and the development of metacognition," *High. Educ.*,2009, vol. 57, no. 5, pp. 609–621, doi: 10.1007/s10734-008-9165-x.

[10] S. Jiusto and D. DiBiasio, "Experiential learning environments: Do they prepare our students to be self-directed, life-long learners?," *Journal of Engineering Education*, 2006, vol. 95, no. 3, pp. 195–204.

[11] K. A. Johnson, S. S. D., S. D. W., and J. R. T., “Pedagogies of engagement: Classroom-based practices,” *J. Eng. Educ.*, 2005.

[12] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, “Engineering design thinking, teaching, and learning,” *Journal of Engineering Education*, 2005, vol. 94, no. 1, pp. 103–120.

[13] E. J. Coyle, L. H. Jamieson, and W. C. Oakes, “2005 Bernard M. Gordon Prize lecture*: Integrating Engineering Education and community service: Themes for the future of engineering education,” *Journal of Engineering Education*, 2006, vol. 95, no. 1, pp. 7–11.

[14] J. E. Froyd and M. W. Ohland, “Integrated Engineering Curricula,” *Journal of Engineering Education*, 2005, vol. 94, no. 1, pp. 147–164.

[15] K. Blair, D. W. Miller, D. Darmofal, C. P. Young, and D. Brodeur, “Problem based learning in aerospace engineering education,” ASEE *Annual Conference Proceedings*, 2002.

[16] A. Gosavi and J. Fraser, “Problem-based learning and Industrial Engineering,” *ASEE Annual Conference & Exposition Proceedings,2013*.

[17] J. T. Bell and H. S. Fogler, “Implementing virtual reality laboratory accidents using the half-life game engine, WorldUp, and Java3D,” *ASEE Annu. Conf. Proc.*, 2003, pp. 10511–10521, doi: 10.18260/1-2--11905.

[18] O. Halabi, “Immersive virtual reality to enforce teaching in engineering education,” *Multimed. Tools Appl.*, 2020, vol. 79, no. 3–4, pp. 2987–3004, doi: 10.1007/s11042-019-08214-8.

[19] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, “A systematic review of immersive virtual reality applications for higher education: Design Elements, lessons learned, and research agenda,” *Computers & Education*, 2020,vol. 147, p. 103778.

[20] M. Nowparvar, X. Chen, O. Ashour, S. Ozden, and A. Negahban, “Combining immersive technologies and problem-based learning in engineering education: Bibliometric Analysis and literature review,” *ASEE Annual Conference Proceedings, 2021*.

[21] R. C. Anderson, W. E. Montague, and R. J. Spiro, *Schooling and the acquisition of knowledge*. ROUTLEDGE, 2019.

[22] D. H. Jonassen, “Objectivism versus constructivism: Do we need a new philosophical paradigm?,” *Educational Technology Research and Development*,1991, vol. 39, no. 3, pp. 5–14.

[23] M. Albanese, “Problem-based learning: Why curricula are likely to show little effect on knowledge and clinical skills,” *Medical Education*, 2000, vol. 34, no. 9, pp. 729–738.

[24] S. B. Merriam, “Andragogy and self-directed learning: Pillars of Adult Learning theory,” *New Directions for Adult and Continuing Education*, 2001.

[25] W. D. K. Jeffry S. Smith, D.T.Sturrock, *Simio and Simulation : Modeling,Analysis, Applications.*, 5th ed. Pittsburgh: Simio LLC, 2018.

[26] Oliver P. John and S. Srivastava, *The Big-Five trait taxonomy : History , measurement, and theoratical*. Berkeley: University of California, 1999.

[27] J. M. Clem, A. M. Mennicke, and C. Beasley, “Development and validation of the experiential learning survey,” *J. Soc. Work Educ.*, 2014, vol. 50, no. 3, pp. 490–506, doi: 10.1080/10437797.2014.917900.

[28] A. Godwin, “*The Development of a Measure of Engineering Identity American Society for Engineering Education*", *ASEE Annual Conference & Exposition Proceedings,2016*.

[29] S. Alaoutinen and K. Smolander, “Student self-assessment in a programming course using Bloom's revised taxonomy,” *Proceedings of the 15th Annual Conference on Innovation and Technology in Computer Science Education, 2010.*

[30] K. O'Reilly, *Ethnographic methods*. London: Routledge, 2011.

[31] K. Charmaz, “Grounded theory,” *The Blackwell Encyclopedia of Sociology*, 2007.