Analyzing Immersive Simulation-based Learning Modules in Remote and In-Person Settings

Abstract

This paper presents a study on the impact of class delivery mode (remote vs. in-person) on students' learning experience when Immersive Simulation-Based Learning (ISBL) modules are used as course assignments. ISBL involves problem-based learning via a 3-dimensional (3D) simulated environment that mimics real-life applications such as manufacturing and healthcare systems, airports, and other service systems. Within the simulated environment, students can observe the corresponding system, collect data, understand relationships between the system components, make changes to the model and observe the impact of those changes, and learn by doing. ISBL is advantageous when access to real-world facilities is difficult or impossible due to geographical barriers or safety concerns as well as in remote and online learning due to geographically dispersed students. This study compares two groups of students. Both groups are taught by the same instructor and use the same course material, including the ISBL modules. The only difference between the two groups is the course delivery mode, where one group is taught remotely through synchronous online sessions, and the other is taught in person in a traditional classroom setting. We collect data on demographics, prior preparation, motivation, experiential learning, usability scale, and self-assessment of learning objectives based on Bloom's taxonomy. We then perform statistical comparisons to investigate the impact of delivery mode when ISBL modules are used. We use the comparison results to test the hypothesis that ISBL modules will help maintain remote students' motivation and learning outcomes compared to in-person students. The results show no statistically significant difference between the two groups on any measure, suggesting that ISBL is equally effective in the two delivery modes.

Introduction and Background

While distance learning and online education offer advantages such as lower cost, increased flexibility, and accessibility beyond geographical barriers, several challenges remain. In [1], four main educational challenges that distance learning presents as compared to in-person instruction are identified which include: reduced social interaction among students, reduced student focus, reduced comprehension and information retention, and limited instructor resources. As a result, online learning is often associated with lower engagement, motivation, and performance [2]. As the number of online programs continues to grow, it is crucial for educational research to assess the effectiveness of pedagogical techniques and emerging technologies that can address the above challenges and make distance learning at least as effective as in-person learning. This paper contributes to this research gap by investigating and comparing the effectiveness of Immersive Simulation-Based Learning (ISBL) environments in online versus in-person delivery mode.

ISBL aims to enhance learning by combining computerized immersive simulations and Problem-Based Learning (PBL). Digital Simulation is commonly used as a powerful analysis tool in various contexts and industry sectors, namely manufacturing [3], healthcare [4], military [5], supply chain [6], and marketing [7]. Therefore, computerized simulation models have the potential to be utilized as a learning tool in many different contexts and disciplines as they provide a virtual and risk-free environment that facilitates experimentation, what-if analysis, and inquiry-based learning [8]. Immersive simulations can enhance affective and cognitive factors such as interest, intrinsic motivation, self-efficacy, embodiment, and self-regulation, and lead to factual, conceptual, and procedural knowledge as well as transfer of learning [9]. PBL, on the other hand, is a well-known active-learning method that supports various theoretical educational and psychological foundations [10, 11, 12] and has a cohesive body of research supporting its effectiveness including for online education [13]. In addition to combining the above two paradigms, ISBL modules are especially suited for online and distance learning as students can perform the learning activity from anywhere, anytime and at their own pace.

In this paper, we investigate whether ISBL can help mitigate the performance gap that is often observed between remote learning and in-person instruction. More specifically, we perform a controlled experiment with two groups of students, where the only difference between the two groups is the course delivery mode such that one group is taught remotely through synchronous online sessions, and the other group is taught in person in a traditional classroom setting. Other factors such as the instructor, course material, and ISBL assignments are common among the two groups. We collect data on demographics, prior preparation, motivation, experiential learning, usability scale, and self-assessment of learning objectives based on Bloom's taxonomy. The results of our statistical comparisons suggest that remote learning with ISBL did not negatively affect students' motivation and learning outcomes. In the following sections, we first define ISBL and summarize supporting theories for its effectiveness. We then describe the course implementations, experimental design, and assessment instruments. Finally, we present the statistical comparisons and conclude the paper by discussing future research extensions.

Immersive Simulation-Based Learning (ISBL)

ISBL involves a PBL activity defined around an immersive simulation environment that serves as the context. The combination of PBL, digital simulation, and immersive technologies makes ISBL a technology-enhanced and contextually-enriched active-learning environment that leverages the advantages of all of the above paradigms to enhance teaching and learning [14]. More formally, an ISBL module consists of:

a. An **immersive virtual environment** that simulates a real system (e.g., a hospital, a manufacturing facility, or an airport). The simulation model mimics the dynamics of the underlying real-world system being modeled and can comprise technical as well as organizational aspects. The simulation also models the products and/or entities that flow in the system and are processed, manufactured, assembled, stored, and transported. The simulation models in our proposed ISBL modules provide realistic animations and can be explored on a 2D display (low-immersion mode) or via a virtual reality (VR) headset (high-immersion mode).

b. A **PBL activity** that mimics real-world problems/projects that arise in the system being modeled, hence resembling situations that learners may encounter at a future workplace.

By treating the immersive simulation environment as a real-world system, both formal and informal learning are enabled by own actions of the learners during and after virtual site visits. In other words, instead of physically visiting a real-world facility, students perform virtual visits of the simulated system to make observations and collect the data and other information needed to complete the PBL activity. This makes ISBL well-suited for remote learning and online education where on-site visits are infeasible due to geographically dispersed students.

Since ISBL combines PBL with an immersive simulated environment, the pedagogical and psychological theories that support PBL also apply to or are enhanced in ISBL. For instance, ISBL activates the principles of the *Constructivism Theory* [15] and the *Information Processing Approach to Learning* theory [16]. This is because ISBL employs an immersive simulation that serves both as a *context* that resembles future professional settings and as an *environment* to interact with – two components that are often missing in traditional engineering education and especially in current online education. This enables the activation of relevant prior knowledge, stimulates learners to elaborate on their knowledge, and allows new knowledge to be constructed via interactions with the virtual environment and indexed by relevant contexts. Moreover, the combination with a PBL activity that is inspired by and resembles a real-world problem, not only makes learning in ISBL a self-directed and problem-centered process that draws on previous experiences, but also facilitates integration into a professional learner's everyday life. These are the pillars of the *Adult Learning Theory* [17] and can enhance professional and continuing education for adult learners, who are predominantly enrolled in online programs.

The interested reader is referred to [18, 19, 20] for sample applications and assessments of ISBL in engineering education, where ISBL is shown to enhance student motivation, experiential learning, and engagement. In addition, ISBL's potential for advanced learning analytics is discussed in [21]. A set of ISBL modules developed as part of our overarching NSF project is publicly available through the project's website at https://sites.psu.edu/immersivesimulationpbl. The immersive simulations used in these modules, including those used in this paper, are developed in the Simio® simulation package [22] which provides realistic animation features and VR compatibility.

Implementation of ISBL Modules in a Database Design Course

For our experiments, we used the *IST 210 - Organization of Data* course offered as part of the Information Sciences and Technology (IST) program at Penn State Abington. This is a 3-credit hour course with two 75-minute lectures per week. The course encompasses requirements gathering and specification, conceptual database design using Entity-Relationship (ER) diagrams, logical database design using relational schema, normalization, and physical database design. In addition, the course discusses the use of *Oracle Application Express* for database-oriented web application development. By the end of the course, students are expected to be able to develop an effective database application satisfying a given set of data requirements. With a structure that allows for both in-person and online instruction, the course comprises group projects, quizzes, homework assignments (four of which are ISBL assignments), and a midterm exam. The samples

Figure 1: A snapshot of the immersive simulation model used in the sample ISBL module

used in our analysis include two sections of remote delivery and two sections of in-person delivery. The same instructor provided identical materials in both delivery modes.

Four ISBL modules are integrated into the course to mimic real-life information technology and database problems. Students are given two weeks to complete each ISBL assignment following the lecture on the respective topic(s). Each ISBL module includes a description of the system and the database problem(s) to be solved. In each module, the students are given a role. For the sake of brevity, we will only describe one of the four ISBL modules here. The ISBL module aims to mimic an internship scenario in which the student is employed to assist in the database design for a company that operates street food kiosks. To gain more knowledge about the system and create an appropriate database design, the student must visit one of the company's hotdog stands located in a small city park. The immersive simulation model is treated as the real-world hotdog stand and has realistic 3D animations to simulate the system and its operation. In other words, students observe and investigate the simulation model instead of physically visiting a real system.

A screenshot of the simulation environment is shown in Figure 1 while Figure 2 depicts the overall logic of the discrete-event simulation model, which can be summarized as follows. The food stand is situated in the middle of a park that has three entrances. Some visitors to the park buy snacks at the food stand (customers), while others just wander around and then exit the park without buying any food. The inter-arrival times of customers, order processing times, and dining times are modeled using random variables. Customers either have their food at the tables in front of the hotdog stand (dine-in) or walk toward an exit after receiving their food (take-out). Dine-in customers choose a table with the fewest number of people (ties are broken arbitrarily). After finishing their meal, customers proceed to the garbage cans to discard any trash before either leaving the park or returning to the stand to order more food.

The PBL activity defined around the simulated context can be summarized as follows. The student is hired as an intern and tasked with analyzing a hotdog stand in Piedmont Park in

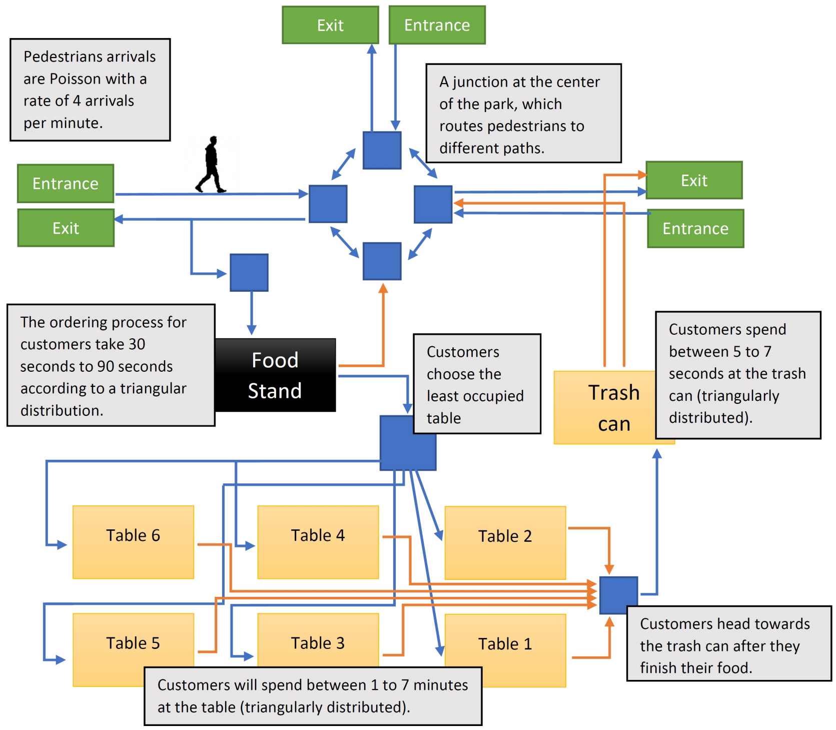

Figure 2: The logic of the hotdog stand simulation model (reprinted with permission from [20])

Atlanta. The student should first familiarize themselves with the system and its operation by examining the simulation. The student will gather and record data based on their observations and will then use the collected information and data from their virtual site visits to develop a database in Excel. The student will then normalize the spreadsheet tables using the database normalization concepts they have learned in the lectures. As for the learning objectives, after successful completion of this ISBL module, the student will be able to:

1. Identify and collect relevant and sufficient data from the system under study for the purpose of creating a normalized database.
2. Determine the appropriate database tables and create the tables in a spreadsheet environment.
3. Decide if normalization is needed for the existing database tables.
4. Apply normalization to the database tables as needed.

Experimental Design and Data Collection Instruments

This study aimed to compare remote and in-person instructional modes on different aspects of student learning outcomes when ISBL learning modules are used. The study was designed as a quasi-experimental study, and data were collected for two separate groups of students, one was taught remotely and the other was taught in person using the same teaching materials and learning modules as well as the same instructor. IRB approval was obtained before the experiment and

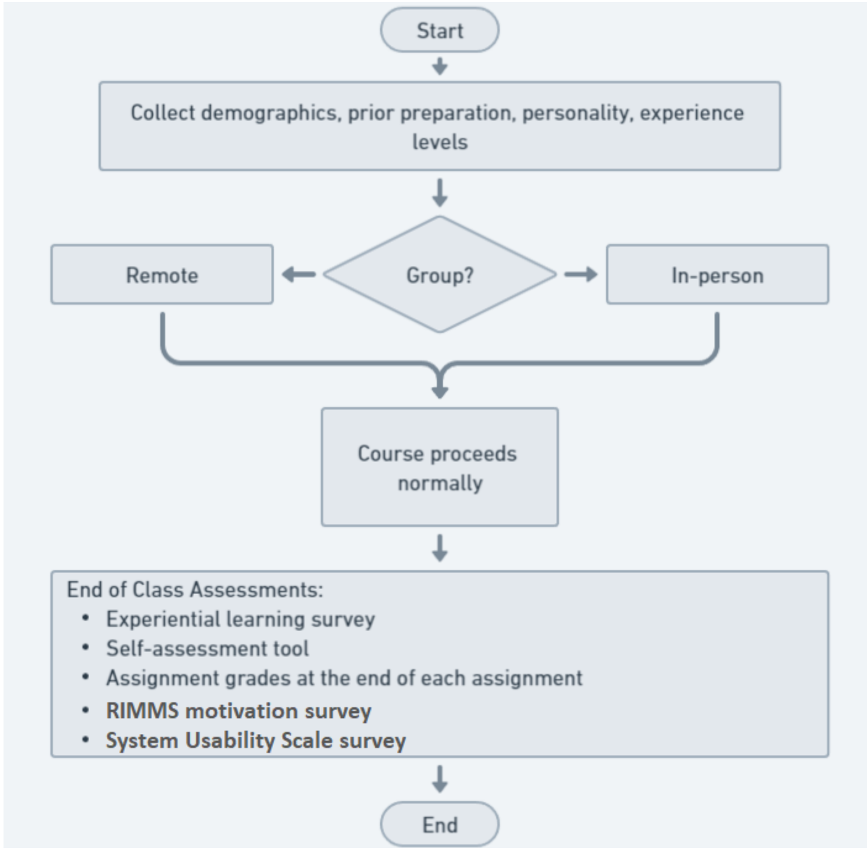

Figure 3: Experimental design and flowchart

data collection. It is hypothesized that any difference between the groups will be attributed to the difference in the delivery mode. Figure 3 shows the experiment flowchart.

The following instruments were used to compare the two delivery modes:

1. Demographics survey: This survey collects data about the student's age, gender, race, grade point average (GPA), grade in a prerequisite course, major, semester standing, work experience, and experience with computer simulation and video games.

2. Big Five Inventory (BFI-10) questionnaire: This instrument is used to determine the student's personality type. The instrument output is the following personality traits: extroversion, agreeableness, conscientiousness, neuroticism, and openness to experience [23].

3. Reduced Instructional Materials Motivation Scale (RIMMS): This instrument is used to measure motivation based on four constructs, namely attention, relevance, confidence, and satisfaction. Each construct has three items in the survey [24].

4. Experiential learning survey: This survey measures the student's perception of their experience in activities that enable learning by doing. We focus on two constructs from this survey, namely *learning environment* and *utility*. The other constructs from the original experiential learning survey [25] are not included because of the overlap with the constructs

measured by the RIMMS motivation survey.

5. Self-assessment survey: This survey is based on Bloom's Taxonomy of learning objectives. It is used to assess students' self-perceived knowledge related to a set of concepts [26]. In this study, students were asked to assess their knowledge of ER Diagrams, Relational Schema, Database Design, and Database Application Development concepts. They rate their knowledge by choosing one of six levels: (1) I can remember related concepts/steps; (2) I can explain related concepts/steps; (3) I can apply this topic/method to a different problem/situation; (4) I can analyze the meaning of the related concepts/steps in the context and why they are there; (5) I can evaluate and ensure the correctness of the use of the related concepts/steps; (6) I can use this topic/method in problem-solving without an example.
6. Assignment grade: All the assignments were graded using a rubric that was created by the instructor to measure the student's achievement in each assignment and understanding of specific concepts. The concepts involved: databases (definition and usage), normalization, entities, relationships, relational schemas, stable and mapped translation methods (ER diagram to relational schema conversion), data dictionary, database application development, and data visualization.
7. System Usability Scale (SUS) survey: The SUS survey is used to measure four types of user experience factors: involvement, immersion, visual fidelity, and interface quality [27]. The survey was used after using a learning module. The outcome of the survey is a single score of usability that ranges between 0 to 100. To understand the calculation procedure, we refer the reader to [28].
8. Open-ended question: Students were asked to answer the following question: *"What changes would you recommend in the Immersive Simulation-based Learning (ISBL) assignments to enhance your learning experience?"*. Our goal was to capture students' feedback to improve the learning modules for future use in online and in-person settings.

Student Population

A total of 43 students participated in the study. The *remote delivery mode* group was composed of 24 students from two sections of the IST 210 course. The *in-person delivery mode* group was composed of 19 students (also from two sections). The students in both groups completed a set of ISBL assignments and a series of surveys and questionnaires as discussed previously. Table 1 shows the summary statistics for the two groups related to demographics as well as work, simulation, and video game experience. To investigate the groups' homogeneity, Chi-squared and t-tests were used, and the results showed no statistically significant differences between the groups in terms of personality traits, age, and grade point average (GPA) at an alpha level of 0.05. The two groups were also similar in terms of the proportion of participants with different gender identities, race, major, semester standing, and their past work, simulation, and video gaming experience levels. Therefore, the two groups can be considered comparable in terms of these measurements.

Table 1: Summary statistics of demographics, and work, simulation, and video game experiences

Variable		**Overall**		**Remote**		**In-person**	
		Freq.	**Prop.**	**Freq.**	**Prop.**	**Freq.**	**Prop.**
Gender	Female	7	0.16	3	0.13	4	0.21
	Male	36	0.84	21	0.88	15	0.79
Race	White	10	0.23	4	0.17	6	0.32
	Hispanic	6	0.14	4	0.17	2	0.11
	Asian	22	0.51	13	0.54	9	0.47
	Black/African American	4	0.09	1	0.04	3	0.16
	Other	1	0.02	2	0.08	0	0.00
Major	Info. Sci Tech.	32	0.74	17	0.71	15	0.79
	Other	11	0.26	7	0.29	4	0.21
Work Experience	No	39	0.91	22	0.92	17	0.89
	Yes	4	0.09	2	0.08	2	0.11
Experience in Simulation	Expert	1	0.02	1	0.04	0	0.00
	Some Experience	24	0.56	15	0.63	9	0.47
	None	18	0.42	8	0.33	10	0.53
Experience in Video Games	Some Experience	18	0.42	9	0.38	9	0.47
	Expert	23	0.53	14	0.58	9	0.47
	None	2	0.05	1	0.04	1	0.05

Research Hypotheses

The experiment in this study investigated the following hypotheses:

1. The use of the ISBL modules helps improve student motivation for the remote delivery mode group by at least making it as close as possible to that of the in-person delivery mode group.
2. The use of the ISBL modules helps improve experiential learning for the remote students by at least making it as close as possible to that of the in-person students.
3. The use of the ISBL modules helps improve student self-assessment scores for the remote group by at least making it as close as possible to those reported by the in-person group.
4. The students in the remote group perform at least as well as the in-person group in terms of understanding of the concepts related to databases as reflected by grades for the ISBL assignments.

Statistical Comparisons and Results

Table 2 provides the mean, median, and standard deviation of the outcomes measured in this experiment. The outcomes include average ISBL assignment grades, score for each motivation construct and the overall motivation, scores for experiential learning constructs *environment* and *utility*, self-assessment scores for each of the four database concepts and the average self-assessment score over all concepts, and the SUS score. To compare the two groups, the non-parametric Mann-Whitney U test is used for cases where the data failed the normality test.

On the other hand, the Welch's t-test (which does not assume equal variances) is used when the samples failed the test for variance equality. Table 2 summarizes the type of test used and the resulting p-values at a 0.05 level of significance. Across all variables, the p-values are greater than 0.05, suggesting that there are no statistically significant differences between the remote and in-person delivery mode groups for these variables. The Mann-Whitney U and Welch's t-test compare the distributions of the two groups. The results suggest that the distributions of scores for ISBL assignment averages, RIMMS scores, experiential learning scores, self-assessment scores, and system usability scores are not significantly different between the remote and in-person groups. The results indicate that the delivery mode of instruction (remote or in-person) did not have a significant impact on these aspects of student learning and experience within the context of this study, supporting the hypotheses posed in the previous section.

Table 2: Statistical comparison

Variable	**Remote**			**In-person**			**Test Used**	**p-value**
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**		
Assignment Avg.	77.07	84.69	23.42	66.44	71.88	26.50	Welch's t-test	0.178
Relevance	9.67	10.50	3.90	11.00	11.00	2.92	Welch's t-test	0.207
Attention	9.33	9.50	3.81	10.47	11.00	2.74	Mann-Whitney U	0.349
Confidence	10.04	10.00	3.76	10.79	11.00	2.70	Mann-Whitney U	0.658
Satisfaction	9.08	10.00	4.28	10.58	11.00	3.08	Mann-Whitney U	0.326
RIMMS-Overall	38.13	40.00	15.08	42.84	43.00	10.64	Mann-Whitney U	0.485
ELE	25.25	26.00	5.99	27.21	28.00	3.22	Welch's t-test	0.178
ELU	36.42	37.00	8.08	38.79	39.00	4.69	Mann-Whitney U	0.264
Self-Assessment1	4.33	4.50	1.49	4.53	5.00	1.65	Welch's t-test	0.693
Self-Assessment2	3.83	4.00	1.20	3.89	5.00	1.82	Welch's t-test	0.900
Self-Assessment3	4.83	5.00	1.40	4.47	5.00	1.39	Welch's t-test	0.407
Self-Assessment4	5.00	6.00	1.40	4.63	5.00	1.61	Welch's t-test	0.464
Self-Assess. Avg.	4.50	4.75	1.33	4.38	4.25	1.19	Welch's t-test	0.745
SUS Score	56.15	62.50	23.42	57.50	55.00	14.07	Mann-Whitney U	0.769

Based on these statistical results, the main finding from this study is that ISBL helped mitigate potential negative effects of remote delivery on students' comprehension, motivation, and performance as previously reported in the literature for traditional remote learning and teaching methods [1, 2].

Conclusions

The aim of this study was to assess the effectiveness of ISBL modules in remote/online and in-person course delivery modes. The key finding of our study is that there are no statistically significant differences in motivation levels and learning achievement among students participating in ISBL, regardless of their learning delivery mode. The results highlight the flexibility of ISBL and demonstrate its potential as an effective tool for online education. This is particularly important in an era where educational paradigms are shifting towards digital and remote modes, and as immersive technologies are gaining more and more traction in educational settings. Our study highlights the benefits of immersive learning experiences in maintaining student engagement and motivation, particularly in online education where these elements are often challenging to sustain. ISBL's ability to simulate real-world contexts offers a unique advantage by providing an interactive and engaging learning experience that traditional remote learning methods often lack.

The proposed ISBL approach addresses critical scalability issues that other immersive technologies commonly used in engineering education generally face. From the learner's perspective, access to special equipment (e.g., VR headsets and powerful graphic cards) is not a requirement since the simulation platform used in our ISBL modules supports both VR and desktop modes of use, allowing the learners to navigate through the simulation model on a typical personal computer or laptop if a VR headset is not available. In addition, the simulation software company provides free licenses to universities, hence there is no technology cost associated with the adoption of ISBL. From the development perspective, the proposed ISBL approach reduces development time and coding effort through the use of a simulation software. Implementing basic simulation logic and processes (e.g., random number generation and sampling, managing discrete events and simulated time, updating and tracking system states, etc.) in common VR platforms (such as the Unreal or Unity game engines) would require excessive programming effort, while these capabilities are built into the simulation software. It is hoped that the above advantages will further encourage the adoption of ISBL by other academic institutions in their online and in-person programs.

Our study contributes to the growing body of evidence supporting the effectiveness of emerging and innovative instructional technologies such as ISBL. As education continues to evolve, the adoption of such technologies will become increasingly important in order to create more inclusive, engaging, and effective learning environments for all learners groups in remote and in-person settings. However, it is important to acknowledge some limitations in our study. The sample size and demographic diversity were constrained, which may limit the generalizability of our findings. In addition, the context of the ISBL learning modules focused on specific course subjects, which would influence the applicability of our results to other disciplines. Future research should aim to expand into these areas, examining the effectiveness of ISBL across multiple subjects and different student populations. In particular, the students in our experiments were predominantly between the ages of 18 and 23. Considering that many online programs (especially at the graduate level) are attended by older adults, expanding the current results to other age groups is an important area for future research. This is critical as previous studies suggest that age is related to learners' performance in immersive virtual environments [29]. It would also be useful to examine the long-term effects of ISBL on engineering identity, knowledge retention and transfer by performing longitudinal studies over multiple years.

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