Proceedings of the 2024 Winter Simulation Conference
H. Lam, E. Azar, D. Batur, S. Gao, W. Xie, S. R. Hunter, and M. D. Rossetti, eds.

THE IMPACT OF IMMERSION LEVEL WHEN LEARNING OPTIMIZATION CONCEPTS VIA A SIMULATION GAME

Saurav Bandi[1], Sabahattin G. Ozden[2], Omar Ashour[3], and Ashkan Negahban[1]

[1]Great Valley School of Graduate Professional Studies, Pennsylvania State University, Malvern, PA, USA
[2]Division of Science and Engineering, Penn State Abington, Abington, PA, USA
[3]Department of Industrial Engineering, Penn State Behrend, Erie, PA, USA

ABSTRACT

Simulation can be employed as an interactive computer game to enable game-based learning. Educational simulations can also be combined with immersive technologies such as virtual reality (VR) to enhance student engagement and learning outcomes further. While recent years have seen significant growth in the use of immersive technologies in education, the role and contribution of the additional immersion offered by VR still needs to be explored. This paper aims to address this gap by comparing low- and high-immersion modes for a simulation game related to fundamental concepts of mathematical optimization. The game resembles performing a heuristic search on the solution space for an optimization problem and involves finding the highest peak in an arctic landscape with three mountains. Our research experiments include three groups of students who play the game in VR, desktop mode, or PowerPoint slides. Our statistical comparisons show that VR enhanced students' sense of presence and learning.

1 INTRODUCTION

Besides its use as an analysis tool in manufacturing (Negahban and Smith 2014), healthcare (Mielczarek and Uzialko-Mydlikowska 2012), military (Naseer et al. 2009), supply chain (Oliveira et al. 2019), and marketing (Negahban and Yilmaz 2014), simulation has also been used for decades as a teaching and learning tool in education and workforce training. Computer simulations provide learners with a low-cost, risk-free experimentation environment that can replace or augment real-world inquiry-based learning experiences. In recent years, with increased availability and affordability of immersive technologies such as virtual reality (VR), there has been a growth in the application of *immersive simulations* in STEM education to utilize the advantages of both paradigms (Negahban 2024). With careful design, immersive simulated environments can be integrated with learning theories to enhance learners' skill development, knowledge acquisition, and knowledge transfer. For instance, based on a recent bibliometric analysis (Nowparvar et al. 2021), one such pedagogical method that can be combined with immersive simulations is Problem-Based Learning (PBL), which is a well-established form of active-learning with a cohesive body of research on its effectiveness (Marra et al. 2014; Onyon 2012; Hmelo-Silver 2004). In a series of studies, the combination of immersive simulations and PBL is found to enhance students' motivation and experiential learning in various topics such as engineering economy (Nowparvar et al. 2022), warehouse design and operation (Estadt et al. 2024), and database design (Ozden et al. 2023; Ozden et al. 2020) as well as in online/remote learning (Ashour et al. 2024). Immersive simulations also support enhanced learning analytics by providing rich navigation and usage data (for example, see Soriano et al. (2023)).

Immersive simulations can be employed as interactive computer games to enable game-based learning and enhance student engagement and interest. This paper presents an example of such a game. More specifically, this paper aims to assess the impact of immersion level and mode of use on the effectiveness of a simulation game for teaching and learning optimization concepts. We implement the game in three modes: VR (played on a head-mounted display), Desktop (played on a desktop computer with a 2D display), and

PowerPoint slides. We then conduct research experiments with three groups of students who play the game in one of the above modes. We use a set of surveys and quiz questions to collect data on students' sense of presence, learning, and motivation under each mode of use. The performance of the three groups is then compared statistically. Considering the development and implementation cost of immersive simulation games due to coding and equipment costs (a VR headset currently can cost hundreds of dollars), it is critical to assess immersion's added value and contribution to inform cost-benefit analysis and justification for using immersive technologies. However, as shown in our literature review in Section 2.2, there is a general lack of understanding of the effect and value of immersion due to the limited number of studies and their mixed findings with some studies indicating a positive effect on learning outcomes with higher immersion, while others showing no improvement or even a negative impact when immersive technologies are used. Through our experiment with different immersion levels and modes of use, this paper contributes to the existing body of knowledge by providing evidence on the effect of immersion when learning occurs via a simulation game. In particular, this paper contributes to Operations Research (OR) education as, to the best of the authors' knowledge, this is the first study on the effect of immersion and animations on students' learning of mathematical optimization concepts via a simulation game.

The remainder of this paper is organized as follows. Section 2 overviews the related literature. Section 3 presents the simulation game and the three modes of use considered in this research. Section 4 describes the experimental design and data collection. Section 5 presents the statistical results on the effect of immersion and mode of use. Finally, conclusions and future research are discussed in Section 6.

2 LITERATURE REVIEW

This section reviews the related literature on simulation games in OR education and the effect of immersion.

2.1 Simulation Games in OR Education

Simulation games are more engaging and motivating for students than traditional lectures, assignments, or case studies. They are more engaging and motivating because games allow students to participate actively in the learning process and see the immediate impact of their decisions. Several studies investigate the effectiveness of simulation games for teaching and learning OR-related topics. For example, Delago et al. (2016) develop a simulation game to teach lean manufacturing. The game focuses on optimizing production processes by getting rid of waste. The game helped students understand and apply the concepts better than traditional lectures. Similarly, Roeder and Miyaoka (2015) find that using simulation games in an introductory operations management course led to better student engagement and performance. Lopez et al. (2021) develop a 3D simulation module for teaching queueing theory and inventory models and investigate its effectiveness in remote versus in-person learning. Their findings suggest that simulation-based learning helped maintain student motivation in remote learning. In another study (Ashour et al. 2022), gamification of a simulation-based learning module is found to enhance students' motivation and learning outcomes in an OR course compared to traditional teaching methods.

In summary, the existing research suggests that simulation games can be valuable tools for teaching and learning OR by bridging the gap between theory and practice and improving student engagement, motivation, and understanding of complex systems. However, more research is needed on the contribution of immersion and realistic animations when learning OR concepts via a simulation game. This paper contributes to this stream of literature by comparing the effectiveness of a simulation game at various immersion levels and modes of use.

2.2 The Effect of Immersion Level

While there are numerous studies on the use of immersive technologies in education as reflected by several review papers (e.g., Radianti et al. (2020), Merchant et al. (2014), Kavanagh et al. (2017)), there are only a few studies on the effect of immersion level on learning outcomes, which involve controlled experiments comparing high- and low-immersion modes (say, VR versus desktop mode). The lack of understanding of immersion's contribution and effect is further compounded by the mixed findings, with papers reporting positive, neutral, and negative effects with higher immersion modes, as exemplified in Table 1. The mixed findings suggest that the effect of immersion can vary depending on the topic. This paper contributes to this stream of literature by providing additional evidence on the impact of immersion level, especially for the topic of optimization, for which no such study currently exists.

Table 1: Studies on the effect of immersion level

Reference	Discipline	Experimental design	Positive impact	Neutral or negative impact
Nersesian et al. (2019)	Chemistry	Compared VR on a head-mounted display (HMD) versus a 2D simulation game on a desktop computer.	Higher final exam and class grades for the VR group although not statistically significant.	VR did not meet students' expectations and their enthusiasm waned over time.
Zhao et al. (2020)	Geosciences	Compared actual field trips, HMD VR, and 360° images for desktop mode.	Improved sense of presence in VR indicated by higher self-location scores.	Motion sickness experienced in VR. No improvement in test scores, representational fidelity, immediacy of control, perceived usefulness and ease of use.
Schuster et al. (2014)	Mechanical engineering	Desktop mode vs HMD VR implemented using a platform called Virtual Theatre.	VR enhanced spatial presence and flow.	More errors in tasks performed in VR.
Shu et al. (2019)	Earthquake and disaster education	Desktop vs HMD VR	Higher spatial presence and mental immersion in VR.	No improvement on earthquake preparedness self-efficacy.

3 DESCRIPTION OF THE LEARNING ACTIVITY AND ENVIRONMENTS

The learning activity that students complete in our experiments resembles searching the solution space for a mathematical optimization problem. The objective is to make an emergency call by finding the highest point in an arctic landscape to maximize signal level. In other words, the arctic landscape represents the solution space of an optimization problem, which can be considered a multidimensional landscape with peaks and valleys. The signal level received at any location in the landscape is a function of elevation such that the signal increases by gaining elevation. Moreover, the signal needs to be stronger than a minimum threshold for the emergency call to go through. Conceptually, the optimization problem can be formulated as follows:

$$\begin{aligned}
&\textit{objective} \quad \text{Make an emergency call by maximizing signal level}\\
&\textit{subject to}\\
&\text{Signal level} \geq \text{Minimum signal (threshold) needed to make an emergency call}\\
&\text{Signal level} = f(\text{Elevation of current location})
\end{aligned}$$

In real-world optimization problems such as those found in supply chains, manufacturing, and healthcare systems, the structure of the solution space is unknown. In addition, due to the complexity of such systems, the solution space for real-world optimization problems can be extremely large, making it impossible to enumerate and evaluate all possible solutions to identify the optimal one. As a result, we often use search algorithms to find the optimal or near-optimal solutions in the vast solution space efficiently by only searching parts of the solution space given limited computational resources/time. Similarly, in the activity, students search different parts of the landscape in the hope of finding the point with enough elevation (hence sufficient signal level) to make an emergency call given the limited food/water supply, which limits how far they can travel in the landscape in the search for the point with the highest elevation. As in the context of an optimization problem, where we perform multiple iterations of the heuristic search process, often starting from a different initial solution in each iteration, the learning activity also involves several iterations. In each iteration, students start from a different location and try to solve the above optimization problem by searching for the highest point near their starting point. The first few iterations of the activity involve following a "greedy" search approach such that students will follow the steepest path from the starting point to climb the nearest mountain, and each time, the greedy approach leads to a local peak that does not provide sufficient signal to make the call. However, the last iteration of the activity initially deviates from the greedy approach. It enables avoiding local optima to reach the highest peak in the landscape from which the emergency call is successfully made.

The above analogies used in the simulation game support the following learning objectives, so that after completion of the activity, the student will be able to:

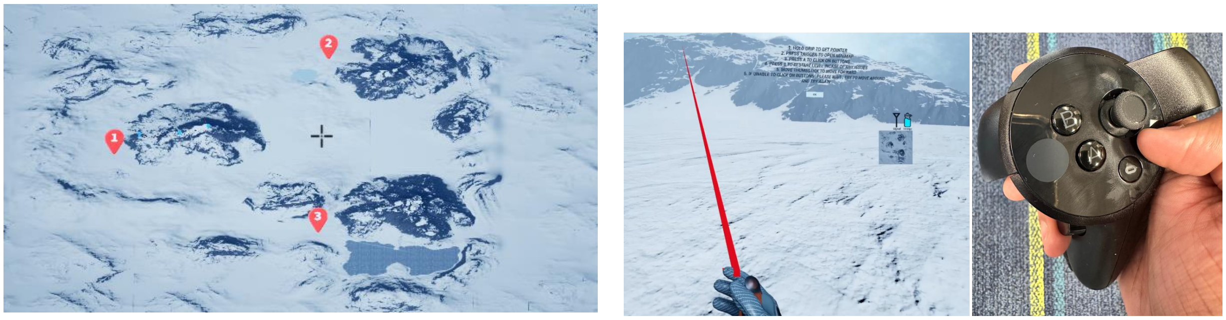
- Identify fundamental optimization concepts such as objective, constraints, solution space, solution fitness, and local optima.
- Explain the effect of modifying the constraints for an optimization problem. For instance, how reducing the minimum threshold for signal level affects the likelihood of a successful search for a location to make the emergency call.
- Explain the effect of change in the computational resources/time available to perform the search. For example, how increasing/reducing the food/water supply affects the ability to search the landscape.
- Compare and contrast different designs for a heuristic search algorithm. For example, performing only one iteration versus multiple search iterations, starting from a random initial solution in each iteration of the search versus starting from the same initial solution but moving in a different direction in each iteration, and greedy search versus random search.

To enable assessing the effect of immersion, we implement the simulation game in three modes: VR mode, Desktop mode, and PowerPoint slides. The following subsections describe the three environments.

3.1 The Simulation Game: VR Mode

The immersive VR environment is shown in Figure 1 and is characterized by a realistic, 4 km by 4 km arctic landscape (drawn to scale) with three mountains, lakes, fog, clouds, and *spatial* audio and sound effects (e.g., the sound of wind and stepping) for added realism and immersion. The environment is developed using the Unreal Engine and can be explored via the Meta Oculus Rift and Meta Oculus Quest 1 and Quest 2 headsets. By wearing the VR headset, participants are transported into this virtual world, where a prompt appears on the screen stating that they are lost during an arctic expedition and need to find enough signal by gaining elevation to make an emergency call. They are also given instructions on how to move around in the environment, where to find the level of food/water left, and how to access a minimap of the landscape that tracks their location as they move. Considering the vast expanse of the landscape, significant time is required to travel between locations by walking. To overcome this challenge, we also include markers or checkpoints that allow participants to instantaneously teleport themselves to specific points upon aiming and clicking on them using a laser pointer. However, each teleportation consumes energy, as indicated by the water supply reduction displayed in the screen's top right corner. Elevation gain increases the signal strength, displayed on the screen's top right side. In optimization terms, the water supply represents the computational budget available to search the solution space, while the signal level represents the objective function value to be maximized. The game is designed to only make the emergency call from the highest peak. Students do not know which of the three mountains has the highest peak in advance.

The simulation game begins by placing the participants at the first starting point near Mountain 1 (representing the first iteration of the search process). The screen prompts instructions to follow a greedy approach by climbing the steepest path up the nearest mountain, i.e., participants search for the marker with the highest elevation and teleport themselves to that location. Upon reaching the peak of the first mountain,



(a) The arctic landscape with three realistically-sized mountains. (b) A sample screenshot of the VR environment.

Figure 1: The VR mode of the simulation game environment.

it becomes apparent that they have depleted their water/food supplies. However, the signal received is still too weak to make an emergency call (representing local optima). A map then appears on the screen, allowing participants to restart, this time from a different starting point near Mountain 2. In the second iteration of the search, participants are again instructed to follow a greedy approach and climb the second mountain. Upon reaching the summit, it becomes evident that while this peak is higher than the previous peak and provides a slightly higher signal level, it still needs to be higher to make the emergency call. In the context of an optimization problem, this represents a case where repeating the search from a different starting solution leads to a better solution but still not the optimal solution. Next, the participants restart from a new starting point near Mountain 3, where they are offered two paths: one that goes up the mountain but eventually leads to a local peak with insufficient signal and another path that first goes around a lake to the other side of the mountain without gaining elevation, however, climbing the mountain from there would lead to the highest (global) peak. This step shows how initially deviating from the greedy approach can help escape local optima. Students are instructed to take the former path first by following the greedy approach. They will then go back to the same starting point, but this time follow the second path around the lake that eventually leads to the highest peak from which they can make the emergency call, and a helicopter arrives to rescue them, as shown in Figure 2.

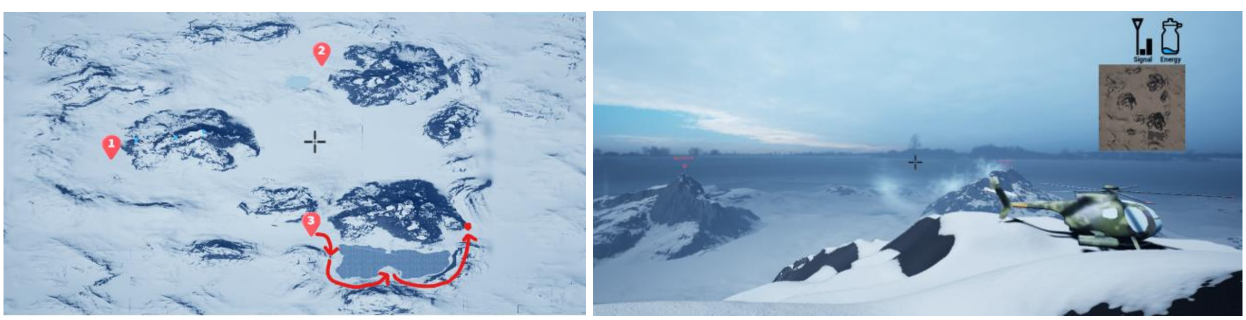


Figure 2: The path that goes around the lake does not lead to elevation gain initially but will eventually reach the highest peak from which the emergency call can be made.

3.2 Desktop Mode

The Desktop mode employed in this research study is the same as the VR environment. The only difference is that it is displayed on a standard 2D screen, and students use the mouse and keyboard to interact with and navigate the landscape, unlike a VR headset and hand controllers. They will also hear the same sound effects but through speakers. All key functionalities and optimization analogies remain the same as in the

VR mode: the signal bar, water supply, minimap, starting points, search iterations, instructions, and text prompts. In essence, the Desktop mode resembles a first-person video game played on a desktop computer.

3.3 PowerPoint Mode

In PowerPoint (PPT) mode, the fundamental concepts and optimization analogies remain consistent with the VR and Desktop modes; however, the entire experience is presented in a set of PowerPoint slides. Participants progress through the game by advancing to the next slide corresponding to the next step in the search for the highest peak. The students hear the same sound effects as in the VR and Desktop modes through the computer's speakers. Figure 3 provides a sample screenshot of the PPT mode.

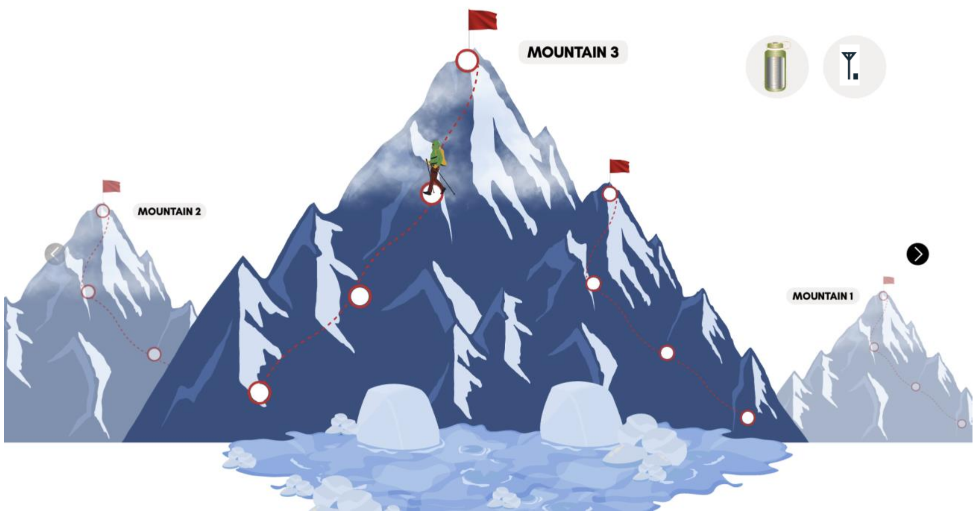


Figure 3: The last iteration of the game in the PowerPoint mode. After reaching the local peak on Mountain 3, the student goes around the lake and climbs the mountain from the other side of the lake, which leads to the global peak where they can make the emergency call.

4 EXPERIMENTS AND DATA COLLECTION

Figure 4 summarizes our study's experimental design and data collection, where the goal is to perform a statistical comparison of the three modes of use described in the previous section. We randomly assign each participant to the VR, Desktop, or PPT group. All students, regardless of their group assignment, complete the same set of surveys and quiz questions to measure their motivation, presence, and learning of the optimization concepts represented in the game. All necessary IRB approvals were obtained prior to conducting the experiments. We used the following instruments for data collection:

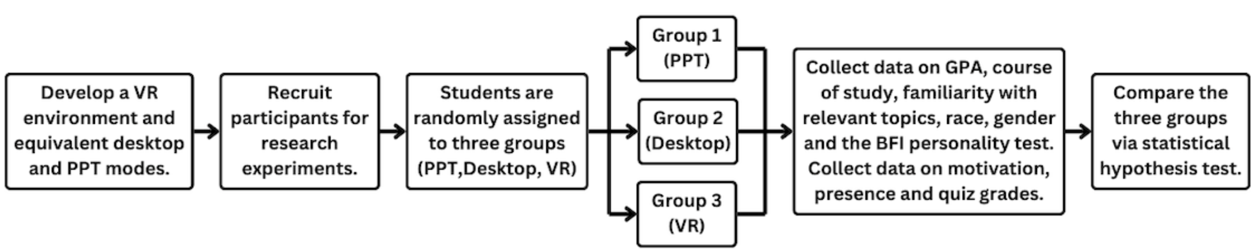


Figure 4: The flow chart of the experimental design and data collection.

- Demographics and Prior Preparation Questionnaire: We collect data on each student's age, gender, race, grade point average (GPA), program of study, semester standing, and prior familiarity with VR, video games, and mathematical optimization. This information is used to establish that the three groups are comparable in terms of their background and prior experience so that any observed group differences can be attributed to the mode of use.
- Big Five Inventory (BFI-10) Personality Test: This is a 10-item version of the Big Five Inventory questionnaire (Smith et al. 2021), and is used to measure the following personality traits: extroversion, agreeableness, conscientiousness, neuroticism, and openness to experiences. This questionnaire enables us to ensure that any observed differences between the three modes are not due to differences in personality traits between the participants in the three groups.
- Presence Questionnaire: Presence is defined as the subjective experience of being in an environment even though one is not physically situated in that virtual environment. It is widely accepted that the effectiveness of virtual learning environments is linked to the sense of presence reported by the users. The presence questionnaire (Witmer and Singer 1998) measures the following categories of factors related to presence: control factors (e.g., possibility to act and navigate), sensory factors (e.g., audio and haptic), distraction factors (related to quality of interface), and realism (encompasses visuals and audio as well as consistency with real-world experiences).
- Reduced Instructional Materials Motivation Scale (RIMMS): This is a 12-item questionnaire (Loorbach et al. 2015) that aims to assess the level of student motivation as measured by the following four constructs: attention, relevance, confidence, and satisfaction.
- Quiz questions: We used a set of questions to assess students' understanding of the learning objectives listed in Section 3. Students responded to the questions in a free text form, and their answers were evaluated using a rubric developed by the research team. The information about the mode of use was hidden during the grading process to eliminate any potential bias in the assessments of students' responses across the three groups.

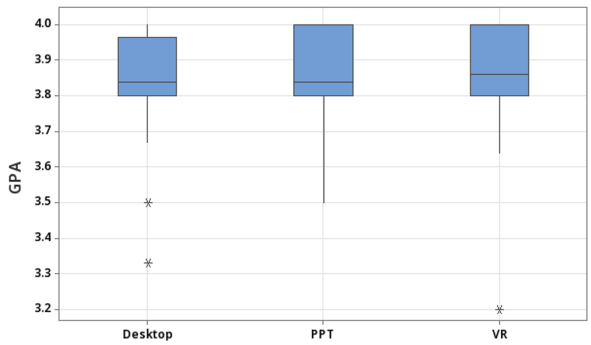
5 STATISTICAL COMPARISONS AND RESULTS

In this section, we first discuss the results related to demographics and prior preparation to establish the baseline and comparability of the three groups of students. We then present the results of statistical tests to compare the three modes in terms of students' presence, motivation, and learning.

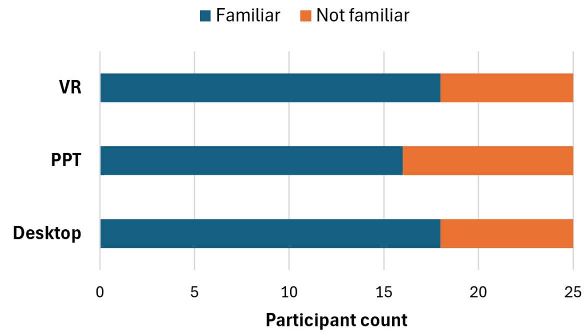
5.1 Student Population and Establishing Comparability

A total of 75 students participated in the study, who were randomly and uniformly assigned to VR, Desktop, and PPT modes, i.e., 25 students per group. All participants are Master's students at the Great Valley School of Graduate Professional Studies at Penn State University. The students are between the ages of 22 and 35 and are from four programs: data analytics, engineering management, software engineering, and MBA. Upon random assignment, the resulting three groups are close in terms of the distribution of their age, race, gender, and academic program. The three groups are also comparable in terms of prior gaming experience as every participant reported that they had played at least one type of game (2D video games such as traditional arcade games, 3D computer games such as first-person video games, VR games played on a head-mounted display, or augmented reality games such as Pokémon GO).

As shown in Figure 5, the three groups are also comparable in terms of the student's GPA and prior familiarity with mathematical optimization. Lastly, we performed statistical tests to compare the three groups in terms of students' scores on the BFI personality traits (i.e., extroversion, agreeableness, conscientiousness, neuroticism, and openness to experiences). Under all personality traits, the results of the Kruskal-Wallis test at a 5% level of significance indicate no statistical difference between the three groups.



(a) GPA comparison.



(b) Prior familiarity with mathematical optimization.

Figure 5: Comparison of the three groups in terms of GPA and prior familiarity with optimization.

Based on the above, the three groups can be considered comparable, and any group differences observed in the following section can be attributed to the intervention (i.e., mode of use) rather than differences in terms of the above factors.

5.2 Results on the Effect of Mode of Use

We perform Kruskal-Wallis tests to compare the three groups regarding presence, motivation, and learning of optimization concepts. All tests are performed at a 5% level of significance using the Minitab statistical software. For the sake of conciseness, the detailed test results are presented only for those factors for which significant statistical differences are detected among the three groups.

While no significant statistical difference was detected between the three groups for motivation-related constructs measured by the RIMMS survey, a significant statistical difference was detected between the three groups in terms of the "Overall Presence" scores as well as scores for the "Realism", "Sound", and "Possibility to Act" constructs as measured by the Presence Questionnaire. Figure 6 summarizes the statistical test results related to presence. In particular, the VR group reports the highest scores for these factors, indicating a higher sense of presence in the VR mode. Interestingly, the PPT and Desktop groups report fairly similar levels of presence, suggesting that the enhanced animation features in the Desktop mode did not make it more effective than the PPT mode in creating a sense of presence in the participants. Considering that the Desktop and VR modes included the same virtual environment and 3D animations, these findings highlight the effect of higher immersion by navigating the simulation game via a VR headset instead of a typical 2D display.

The better performance of the VR group can be attributed to the higher *degree of freedom* in users' input, *stereoscopy* (i.e., adding an illusion of depth to an image), and the level of *immersion* (i.e., fidelity and technological quality), which have been shown to be significant factors according to a meta-analysis of the effect of immersive technology on user presence (Cummings and Bailenson 2016). Head-mounted display VR devices deliver the utmost levels of immersion and allow the user to freely adjust their viewpoint by moving their head in any direction in a natural way, while the Desktop mode offers a less immersive experience with limited freedom and unnatural navigation means (e.g., the user has to move the mouse to look around in the virtual environment). The use of a head-mounted display enables an authentic 360-degree VR experience with a realistic sense of 3D and depth. While the Desktop mode also allows for 360-degree observation, a sense of depth is lacking in the visuals due to projection on a 2D screen. The enhanced visual and auditory cues offered by a VR headset increase the sensory fidelity and foster a convincing illusion of "being there" in the virtual environment, explaining why the Desktop group reports a lower sense of presence compared to the VR group despite using the same sound effects for all modes of use in our experiments. Therefore, the results indicate that impression attributes (e.g., visual and overall realism) and sound attributes (e.g., spatial sound) have a significant impact on presence.

Descriptive Statistics

Group	N	Median	Mean Rank	Z-Value
PPT	25	107	30.0	-2.24
Desktop	25	109	36.4	-0.45
VR	25	120	47.6	2.69
Overall	75		38.0	

Test

Null hypothesis H_0: All medians are equal
Alternative hypothesis H_1: At least one median is different

Method	DF	H-Value	P-Value
Not adjusted for ties	2	8.32	0.016
Adjusted for ties	2	8.32	0.016

(a) Test results for the "Overall Presence" score.

Descriptive Statistics

Group	N	Median	Mean Rank	Z-Value
PPT	25	33	30.1	-2.22
Desktop	25	35	37.2	-0.24
VR	25	40	46.7	2.46
Overall	75		38.0	

Test

Null hypothesis H_0: All medians are equal
Alternative hypothesis H_1: At least one median is different

Method	DF	H-Value	P-Value
Not adjusted for ties	2	7.34	0.025
Adjusted for ties	2	7.36	0.025

(b) Test results for the "Realism" construct.

Descriptive Statistics

Group	N	Median	Mean Rank	Z-Value
PPT	25	14	33.7	-1.20
Desktop	25	14	31.1	-1.93
VR	25	18	49.1	3.13
Overall	75		38.0	

Test

Null hypothesis H_0: All medians are equal
Alternative hypothesis H_1: At least one median is different

Method	DF	H-Value	P-Value
Not adjusted for ties	2	9.97	0.007
Adjusted for ties	2	10.06	0.007

(c) Test results for the "Sound" construct.

Descriptive Statistics

Group	N	Median	Mean Rank	Z-Value
PPT	25	19	31.5	-1.82
Desktop	25	21	35.9	-0.58
VR	25	22	46.5	2.39
Overall	75		38.0	

Test

Null hypothesis H_0: All medians are equal
Alternative hypothesis H_1: At least one median is different

Method	DF	H-Value	P-Value
Not adjusted for ties	2	6.24	0.044
Adjusted for ties	2	6.29	0.043

(d) Test results for the "Possibility to Act" construct.

Figure 6: Statistical comparison of the three groups in terms of the constructs measured by the Presence Questionnaire. All results are based on the Kruskal-Wallis test at a 5% level of significance.

As mentioned previously, we assess students' learning through a set of quiz questions related to the learning objectives mentioned in Section 3, namely the effect of changing the constraints and computational resources and enhancing the design of a heuristic search method. Students answered five questions in a free text format and were asked to clearly explain and justify their responses. Their answers were graded consistently across all participants using a rubric created by the researchers and also in a *blind* fashion, meaning that the student's mode of use and other identifying information were removed to avoid any potential bias during the grading process. While the Kruskal-Wallis test did not reject the equality of the median grade for the three groups, further analysis of the distribution of quiz grades shows an improvement in students' performance as we go from PPT to Desktop and from Desktop to VR mode. As shown in Figure 7, 64% of the students in the PPT group scored 40 or less on the quiz, while for the Desktop and VR groups, this was 48% and 40%, respectively. The better learning performance of the VR group can be attributed to (a) the stronger sense of presence, which can significantly increase the effectiveness of a teaching method as higher presence is shown to enhance students' focus and active engagement (Wertzberger 2019); and, (b) learning via immersive VR is shown to enhance students' cognitive and affective factors (Makransky and Petersen 2021), hence better understanding of complex concepts such as those that arise when learning about searching the solution space of an optimization problem.

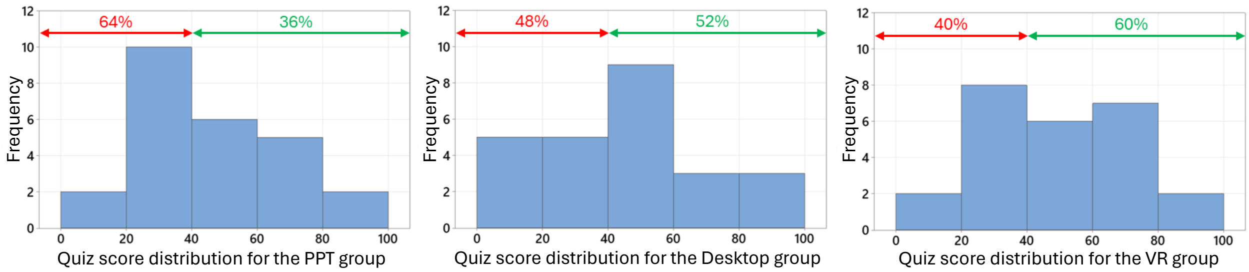


Figure 7: Histogram of quiz scores for the three groups.

6 CONCLUSIONS

In this paper, our goal was to assess the role and contribution of the additional immersion offered by VR on students' performance when learning fundamental concepts related to mathematical optimization via a simulation game. To that end, we designed a simulation game that resembled performing a heuristic search on the solution space for an optimization problem. More specifically, the game involved searching an arctic landscape containing multiple mountains to find the highest peak. We conducted research experiments with three groups of students who played the game either in VR, desktop mode, or PowerPoint slides. After establishing that the three groups were comparable in terms of students' age, gender, race, grade point average (GPA), program of study, semester standing, and prior familiarity with VR, video games, and mathematical optimization, our statistical comparisons revealed two important findings: (a) the close performance of desktop and PowerPoint groups suggest that the enhanced animation features in the desktop mode did not have a significant impact; and, (b) the high level of immersion offered by VR enhanced students' sense of presence and learning of optimization concepts.

There are many other aspects of the impact of immersion that future research can investigate. For example, a longitudinal study can be performed to assess the effect of immersive simulation-based learning modules on engineering identity. A comparison with real-world experiences would provide insight into the effectiveness of immersive simulation games in terms of experiential learning. Moreover, the impact of immersion on student engagement can be explored by analyzing and comparing learner-simulation interactions in high- and low-immersion modes. This can be done by analyzing screen-recorded videos of learners' navigation and interactions in the virtual environment. For example, the time spent in the simulation, distance traveled, and head movement (i.e., how much students look around) can be used as measures of engagement when comparing low- and high-immersion modes of use.

Considering that many commercial simulation packages nowadays offer 3D animation features and compatibility with VR, there is an abundance of opportunity for the simulation community to use the models developed as part of their technical research and industry projects for teaching and learning purposes as well as educational research related to immersive simulation-based learning approaches. For an example of such efforts, see the website for the NSF project associated with this paper at https://sites.psu.edu/immersivesimulationpbl. We hope that this work will further encourage simulationists to pursue such possibilities.

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No. 2000599. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We want to thank Parhum Delgoshaei for helpful conversations and valuable feedback.

REFERENCES

Ashour, O., S. G. Ozden, and A. Negahban. 2024. "Analyzing Immersive Simulation-based Learning Modules in Remote and In-Person Settings". In *Proceedings of the ASEE Annual Conference and Exposition*.

Ashour, O., A. Seamon, C. Lopez, S. G. Ozden, D. DiFrancesca and C. Tucker. 2022. "A Study on the Effectiveness of using Integrated Nonlinear Storytelling and Simulation-based Learning Game in an Operations Research Course". In *Proceedings of the ASEE Annual Conference and Exposition*.

Cummings, J. J. and J. N. Bailenson. 2016. "How Immersive Is Enough? A Meta-Analysis of the Effect of Immersive Technology on User Presence". *Media Psychology* 19(2):272–309.

Delago, L. C., M. E. Machado, F. O. de Brito, G. C. Landgraf, M. D. A. Schroeder and C. Torezzan. 2016. "Learning lean philosophy through 3D game-based simulation". In *2016 Winter Simulation Conference (WSC)*, 3385–3392. IEEE.

Estadt, E. J., H. Nguyen, K. S. Stuart, J. Delva, A. Negaban, O. Ashour *et al*. 2024. "Warehouse Augmented Reality Program (WARP): A Web Tool for Warehouse Design and Operation Education". In *Proceedings of the ASEE Annual Conference and Exposition*.

Hmelo-Silver, C. E. 2004. "Problem-Based Learning: What and How Do Students Learn?". *Educational Psychology Review* 16(3):235–266.

Kavanagh, S., A. Luxton-Reilly, B. Wuensche, and B. Plimmer. 2017. "A systematic review of virtual reality in education". *Themes in Science and Technology Education* 10(2):85–119.

Loorbach, N., O. Peters, J. Karreman, and M. Steehouder. 2015. "Validation of the Instructional Materials Motivation Survey (IMMS) in a self-directed instructional setting aimed at working with technology". *British Journal of Educational Technology* 46(1):204–218.

Lopez, C., O. Ashour, J. Cunningham, and C. Tucker. 2021. "A Study on the Effectiveness of the CLICK Approach in an Operations Research Course". In *Proceedings of the ASEE Annual Conference and Exposition*.

Makransky, G. and G. B. Petersen. 2021. "The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality". *Educational Psychology Review* 33:937–958.

Marra, R. M., D. H. Jonassen, B. Palmer, and S. Luft. 2014. "Why Problem-Based Learning Works: Theoretical Foundations". *Journal on Excellence in College Teaching* 25(3&4):221–238.

Merchant, Z., E. T. Goetz, L. Cifuentes, W. Keeney-Kennicutt and T. J. Davis. 2014. "Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis". *Computers & Education* 70:29–40.

Mielczarek, B. and J. Uzialko-Mydlikowska. 2012. "Application of Computer Simulation Modeling in the Health Care Sector: A Survey". *SIMULATION* 88(2):197–216.

Naseer, A., T. Eldabi, and M. Jahangirian. 2009. "Cross-Sector Analysis of Simulation Methods: A Survey of Defense and Healthcare". *Transforming Government: People, Process and Policy* 3(2):181–189.

Negahban, A. 2024. "Simulation in engineering education: The transition from physical experimentation to digital immersive simulated environments". *SIMULATION* 100 https://doi.org/10.1177/00375497241229757.

Negahban, A. and J. S. Smith. 2014. "Simulation for Manufacturing System Design and Operation: Literature Review and Analysis". *Journal of Manufacturing Systems* 33(2):241–261.

Negahban, A. and L. Yilmaz. 2014. "Agent-Based Simulation Applications in Marketing Research: An Integrated Review". *Journal of Simulation* 8(2):129–142.

Nersesian, E., A. Spryszynski, and M. J. Lee. 2019. "Integration of Virtual Reality in Secondary STEM Education". In *2019 IEEE Integrated STEM Education Conference (ISEC)*, 83–90 https://doi.org/10.1109/ISECon.2019.8882070.

Nowparvar, M., O. Ashour, S. Ozden, D. Knight, P. Delgoshaei and A. Negahban. 2022. "An assessment of simulation-based learning modules in an undergraduate engineering economy course". In *Proceedings of the ASEE Annual Conference and Exposition*.

Nowparvar, M., X. Chen, O. Ashour, S. G. Ozden and A. Negahban. 2021. "Combining immersive technologies and problem-based learning in engineering education: Bibliometric analysis and literature review". In *Proceedings of the ASEE Annual Conference and Exposition*.

Oliveira, J., M. Jin, R. Lima, J. Kobza and J. Montevechi. 2019. "The role of simulation and optimization methods in supply chain risk management: Performance and review standpoints". *Simulation Modelling Practice and Theory* 92:17 – 44.

Onyon, C. 2012. "Problem-based learning: a review of the educational and psychological theory". *The Clinical Teacher* 9(1):22–26.

Ozden, S., A. Negahban, O. Ashour, and D. Knight. 2023. "Investigating the Impact of Context Choice on Learning Experience via Immersive Simulations in an Object-Oriented Programming Course". In *Proceedings of the ASEE Annual Conference and Exposition*.

Ozden, S. G., O. M. Ashour, and A. Negahban. 2020. "Novel simulation-based learning modules for teaching database concepts". In *Proceedings of the ASEE Annual Conference and Exposition*.

Radianti, J., T. A. Majchrzak, J. Fromm, and I. Wohlgenannt. 2020. "A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda". *Computers & Education* 147:103778.

Roeder, T. M. K. and J. Miyaoka. 2015. "Using simulation as a teaching tool in an introductory operations management course". In *2015 Winter Simulation Conference (WSC)*, 3481–3489 https://doi.org/10.1109/WSC.2015.7408508.

Schuster, K., M. Hoffmann, U. Bach, A. Richert and S. Jeschke. 2014. "Diving in? how users experience virtual environments using the virtual theatre". In *Design, User Experience, and Usability. User Experience Design for Diverse Interaction Platforms and Environments: Third International Conference, DUXU 2014, Held as Part of HCI International 2014, Heraklion, Crete, Greece, June 22-27, 2014, Proceedings, Part II 3*, 636–646. Springer.

Shu, Y., Y.-Z. Huang, S.-H. Chang, and M.-Y. Chen. 2019. "Do virtual reality head-mounted displays make a difference? A comparison of presence and self-efficacy between head-mounted displays and desktop computer-facilitated virtual environments". *Virtual Reality* 23:437–446.

Smith, M. L., D. Hamplová, J. Kelley, and M. Evans. 2021. "Concise survey measures for the Big Five personality traits". *Research in Social Stratification and Mobility* 73:100595.

Soriano, N., A. Negahban, S. Ozden, and O. Ashour. 2023. "An Open Source Video Analytics Tool for Analyzing Learner Navigation in Immersive Simulated Environments". In *Proceedings of the Annual Modeling and Simulation Conference (ANNSIM)*.

Wertzberger, E. 2019. "The Future of Field Experiences in Distance Education: A Case Study of Co-Teaching Practices in a Telepresence-Facilitated Field Placement". *Theory & Practice in Rural Education* 9(2):35–46.

Witmer, B. G. and M. J. Singer. 1998. "Measuring Presence in Virtual Environments: A Presence Questionnaire". *Presence: Teleoperators and Virtual Environments* 7(3):225–240.

Zhao, J., P. LaFemina, J. Carr, P. Sajjadi, J. O. Wallgrün and A. Klippel. 2020. "Learning in the Field: Comparison of Desktop, Immersive Virtual Reality, and Actual Field Trips for Place-Based STEM Education". In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 893–902 https://doi.org/10.1109/VR46266.2020.00012.

AUTHOR BIOGRAPHIES

SAURAV BANDI is a Graduate Research Assistant and Master of Engineering Management student at The Pennsylvania State University, Great Valley School of Graduate Professional Studies. He has a Bachelors of Technology in Electrical, Electronics, and Communications Engineering from Jawaharlal Nehru Technological University, India. His email address is sfb5972@psu.edu.

SABAHATTIN G. OZDEN is an Assistant Professor of Information Sciences and Technology at Penn State Abington. He received B.S. degree in Software Engineering with a double major in Industrial Systems Engineering from Izmir University of Economics in 2009. He received his Master of Industrial and Systems Engineering and a Ph.D. degree in Industrial and Systems Engineering from Auburn University in 2012 and 2017, respectively. His research interests are warehousing, optimization, and information systems. His email address is gokhan@psu.edu and his website is https://www.gokhanozden.com.

OMAR ASHOUR is an Associate Professor of Industrial Engineering at Pennsylvania State University, The Behrend College. He received a B.S. degree in Industrial Engineering/Manufacturing Engineering and an M.S. degree in Industrial Engineering from Jordan University of Science and Technology (JUST) in 2005 and 2007, respectively. He received his M.Eng. degree in Industrial Engineering/Human Factors and Ergonomics and a Ph.D. degree in Industrial Engineering and Operations Research from The Pennsylvania State University (PSU) in 2010 and 2012, respectively. Dr. Ashour was the inaugural recipient of William and Wendy Korb Early Career Professorship in Industrial Engineering in 2016. His research areas include data-driven decision-making, modeling and simulation, data analytics, immersive technologies, and process improvement. He contributed to research directed to improve design and engineering education. Dr. Ashour currently serves as a Technical Vice President (TVP) on the Technical Operations Board (TOB) of the Institute of Industrial and Systems Engineers (IISE). His email address is oma110@psu.edu.

ASHKAN NEGAHBAN is an Associate Professor of Engineering Management at The Pennsylvania State University, Great Valley School of Graduate Professional Studies. He received his Ph.D. and master's degrees from Auburn University (USA) and his BS from University of Tehran (all in Industrial and Systems Engineering). His research involves stochastic simulation methods, primarily agent-based and discrete-event simulation. He also conducts research related to novel simulation-based learning environments in STEM education. His email and web addresses are aun85@psu.edu and https://ashkannegahban.com.