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Experiential Learning in Virtual Realities

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Abstract

Immersive simulations are powerful teaching tools, particularly useful for subjects where a holistic understanding of a complex system is necessary. The authors have used several 6-hour table-top simulations to teach process improvement and engineering courses at Northeastern, George Washington, and Loyola Marymount universities. The pandemic forced a natural experiment. On-line versions of the simulations were created in commercially available software which recreated the experience of the in-person simulations directly, with almost all actions, lessons, discussion and planning sessions preserved. More than 120 students participated in the on-line simulations in 2020 and 2021. Before and after the pandemic (and during it, in hybrid classes), a large "control" group of students participated in the in-person simulations. Extensive data was collected including self-reported student learning, instructor evaluations of student performance and data from the simulations themselves. On-line simulations were assessed by students to be less effective overall by a small but statistically significant amount, but on most specific aspects of learning, and on student outcomes, there was no significant difference between them and the in-person versions. The existing difference depended on the degree of immersion in the simulation; fully immersive simulations were assessed to be fully as effective as in-person simulations. The virtual simulations were *more* work to facilitate. The overall experience is a proof-of-concept that virtual simulations can take the place of even complex in-person simulations with little loss of pedagogical effectiveness. The challenge is now to refine the simulations so that the need for faculty facilitation is reduced, and the level of immersion increased.

Introduction

Simulations are somewhere between useful and necessary for teaching the behavior of complex systems [1]. Simulations allow students to observe and manipulate systems, experience their often-non-intuitive behavior, and try out different approaches for affecting and/or improving that behavior. Integration of simulations into teaching allows theoretical lessons to be demonstrated and experienced by the students [2-4]. Giving the students a goal within a simulation can create a "game" which both motivates thinking and increases enjoyment and engagement [5, 6]. Simulations are in fact widely used in teaching manufacturing systems, engineering systems and design, engineering management, health care systems, and lean six-sigma process improvement; all subjects in which students need to gain an understanding of complex systems.

Many teaching simulations are implemented physically, as laboratory or table-top systems. These simulations have the advantage of being direct (if often simplified and miniaturized) models of the systems in question, allowing tactile learning from manipulating the simulation elements, and fostering face-to-face teamwork by the participating students. The idea of implementing such simulations in *virtual* environments seems promising. Theoretically, these implementations should be cheap, easy to implement, and universally available to students. A large amount of work has been done in this area, but success has been difficult to quantify [7].

During the Covid-19 pandemic, an interesting natural experiment occurred. Out of necessity, a well-established and widely used set of physical simulations used to teach engineering systems, lean process improvement and lean healthcare were replicated in off-the-shelf commercially available virtual environments. These virtual simulations were used for several years (and in some cases are still in use) as part of courses at three universities. They were used in the same classes, in the same way, to teach the same lessons, as their in-person counterparts. As part of on-going class assessment efforts, data was collected on student satisfaction, self-reported learning, and class performance for both sets of simulations. This paper will describe the simulations, and report on the evaluations of the two modes.

Simulations

The three original simulations were designed to teach similar lessons, but for different audiences. They were originally created at the MIT Lean Advancement Initiative, for the LAI Lean Academy courses [8]. Teams of designers, academics, and professional trainers from the aerospace industry and health care organizations created and refined the simulations; they have been in use at many organizations since 2008 or earlier. In all three simulations, 5-7 students take specific roles in an organization and have to work together to execute complex and interdependent tasks. The simulations include a manufacturing and supply chain version, in which the students build LEGO® airplanes [9]; an engineering and product development version, in which the students process paper "jobs;" and a health care clinic version, in which the students treat LEGO patients.

Over the course of a six hour session, the students improve their work practices, communication and coordination, and improve and redesign their organization, to drastically increase their productivity. This is done in structured rounds in which tools such as workplace organization (5S), Value Stream Mapping and Analysis (VSMA), and advanced systems for workflow are used to make the simulated process progressively better. All the simulations share this basic structure. They also share common elements such as the use of sand timers to control the pace of the work, dice to introduce randomness, and specific roles for each student with simple rules on printed mats on the table. Table 1 shows the elements of the three simulations, and the nature of the improvement rounds, and Figure 1 shows some of the physical elements handled in the simulation.

In the manufacturing simulation, four students create tails, wings, fuselage, and do final assembly of a LEGO airplane. Their pace is controlled by sand timers to prevent a LEGO-building race. Two other students bring them the parts they need through an initially cumbersome supply chain. Students overcome physical difficulties with 5-S, training, and standard work. They then redesign the assembly process for balance and flow. In a final round they do a design-for-manufacturing exercise to create a new, more buildable design, and use pull, kitting, and kanban tools to create a lean manufacturing system that can typically make five times as many airplanes as the start state with basically the same resources.

The product development simulation involves 7 students taking the roles of project management, design, analysis, systems engineering and verification and testing. They process several different kinds of paper jobs that have different paths through the system. They perform abstract tasks, attaching labeling dots to the paper “jobs,” with time controlled by sand timers and success or failure determined by dice. Failure can create rework, which in turn can create queues and chaos. Standard and visual work, and strategic addition of resources at bottlenecks, allows the system to perform better and more predictably. A final round of refined work roles, with the systems engineers doing upfront risk management, and functions participating in concurrent engineering, allows the system to work very well and overcome a final “challenge round” that would have been impossible for the initial organization to handle.

The healthcare simulation has 6 students playing the roles of scheduler, receptionist, triage nurse, examining MD, diagnostic technician, and discharge aide at a somewhat abstract clinic that could represent an outpatient, urgent care, or emergency room situation. LEGO patients take various paths through the clinic, with their differing needs signaled by the colors of their various parts. At each step they are “treated” with success and timing determined by dice and sand timers. Results are recorded on cumbersome paperwork. The system is improved by standardizing work, cross-training personnel, and finding more efficient paths through the system for some patients. A final round focuses on training and technology upgrades to lower variability and thus make the process more predictable, and redesigning the medical record system so that it can keep up with the fast pace of the improved system. The result is both higher productivity and a better “patient” experience.

More information on the simulations may be found in previous reports on their use [10-12]. Video demonstrations of two of the simulations are available on the MIT Open Courseware site [13].

Table 1. Characteristics of Simulations

Simulation	Manufacturing	Engineering	Healthcare
Goal	Build LEGO airplanes	Process paper jobs	Treat LEGO patients
Number of students	6	7	6
Roles	Component manufacturing, supply chain	Engineering and management functions	Healthcare and administrative functions
Challenges	Physically assemble planes, handle parts and paperwork	Process jobs in with mix model work and high process variation	Handle different patient needs and high variation processes
Initial Improvements	5S, Visual work, communication	5S, Visual work, communication	5S, Visual work, communication
Improved State	Capacity analysis, balance work, supply chain coordination	VSMA, balance capacities, coordinate and prioritize work	VSMA, balance workflows, meeting individual patient needs
Future State	High Takt pace, Just-In-Time, design for manufacturing, standardized work	Reduce variation, advanced organization, rapid iteration, adaptable workflow	Reduce variation, enterprise integration, rapid and adaptable workflow

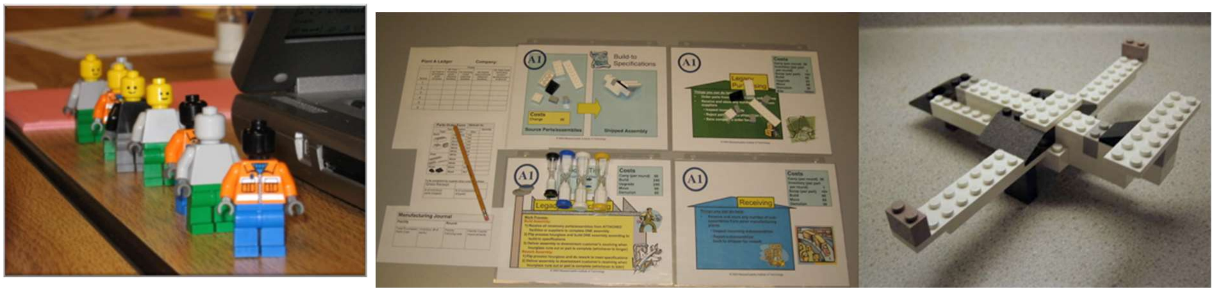

Figure 1. Elements of in-person simulations: LEGO “patients,” gaming mats with rules, timers, and paperwork, LEGO airplane.

Creation of Virtual Reality Simulations

Virtual versions of the simulations were created in haste in the summer and fall of 2020. Off-the-shelf software was used. The Minecraft software [14] creates an immersive 3-D world where participants control avatars that can move around and build things out of a wide range of standard components. The components can be picked up, loaded into chests and carts, and used to create arbitrary objects. The educational edition of Minecraft includes the ability to host multiple players in a Minecraft “world” and restrict their abilities in various ways. The Minecraft world is immersive (the player avatars walk around in a 3-D environment) but lacks realistic physics (for example, the blocks pop from the player’s backpack onto the plane with a gesture). Tabletop Simulator [15] creates a more limited world, consisting only of a gaming table. Players are represented by static icons “sitting” around the table. Each player has an active hand that can manipulate objects in a variety of ways, and an eye (or “camera”) that can move around and examine objects on the table. Games can be created out of various combinations of both standard components (such as playing cards and chess pieces) and custom items. Although limited, the tabletop has objects with realistic physics: dice can be rolled, cards flipped, and chess pieces picked up, put down, or tipped over. The physics is not fully realistic; for example, the cards can be made “sticky” so that they are easier to handle with one hand (which is all you have in the simulation).

Minecraft was used to create an aircraft factory, in which the players build airplanes out of Minecraft blocks and other components. The LEGO aircraft was translated into Minecraft with only a minor redesign. The supply chain of LEGO blocks and carrying bins was simulated in Minecraft with Minecraft blocks contained in chests and carried in backpacks or carts. The timers that regulated the pace of assembly in the LEGO simulation were replicated in Minecraft by chests controlled by redstone circuitry (an in-game control mechanism) that released blocks at a fixed pace, limiting how quickly students could build the airplanes. The design-for-manufacturing exercise was directly implemented in a sandbox area where the students redesigned the Minecraft airplane. Figure 2 shows some views of the Minecraft simulation. Creating this simulation took several months of work by student teams, and went through several iterations and debugging cycles to be ready for the students.

The engineering and healthcare simulations were re-created in Tabletop simulator. The translation was fairly direct – the printed rules mats (slightly updated) were transferred to the virtual tabletop, as were the dice. Customized playing cards were used to replace the paperwork, and the diverse LEGO people were replaced with various chess pieces. The sand timers were replaced by small clock timers in the simulation, but their function remained the same. Figure 3 shows some views of the healthcare simulation as implemented in table-top simulator. These implementations were surprisingly easy, taking only a few days of labor, most of it relatively unskilled (e.g. typing up playing cards).

Figure 2. Minecraft aircraft factory. Clockwise from upper left: Aerial view of factory; production bay with aircraft built from Minecraft blocks; student avatars working on a design; "supplier" getting blocks from a timed chest.

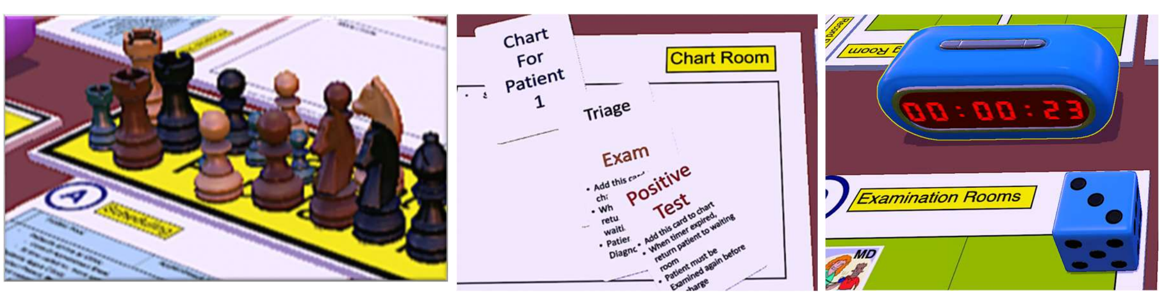

Figure 3. Elements of Tabletop Simulator clinic: Chess piece "patients," paperwork cards, in-game timers and dice.

In all cases, some other off-the-shelf solutions were required for support. Zoom was used for presentations, and for students communication with staff and each other. Accounting paperwork was done in Google sheets; brainstorming and value stream mapping was done in Miro. Again, these tools allowed use of existing materials with little or no modification. Figure 4 shows a student value stream map created in the Miro software.

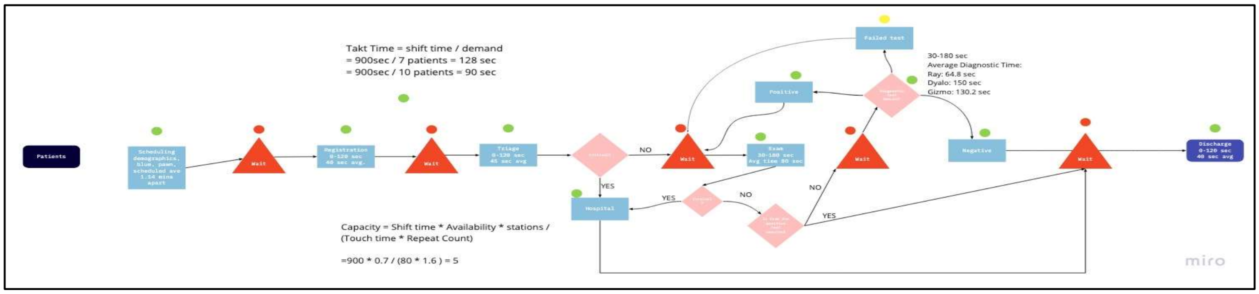

Figure 4. Value stream map created in Miro

Table 2 summarizes some of the characteristics of the virtual simulations. The direct translation of the simulations to the virtual reality worlds allowed the actual running of the simulations, the exercises and lessons, and the challenges and improvements to remain unchanged from the real-world versions. In both modes, some introduction and training was required, which was of course different in the virtual reality. The game roles, lessons, challenges, and improvement states in Table 1 applied directly to the virtual simulation in all cases.

Table 2. Characteristics of Virtual Simulations

Simulation	Manufacturing	Engineering	Healthcare
Software	Minecraft	Tabletop simulator	Tabletop simulator
World	Large 3-D factory	Table	Table
Student Presence	3-D walking avatar	Hand and camera	Hand and camera
Student Actions	Walk around world, move and place blocks, build and demolish scaffolding	Handle card decks (draw, flip, arrange, and pass) roll dice, run timers	Move chess pieces, handle card decks (draw, flip, arrange, and pass) roll dice, run timers
Physics	Magical (gestures and tools “pop” blocks around)	Semi-realistic	Semi-realistic
Game elements	Block airplanes, chest/cart/backpack supply chain	Paper jobs represented as custom card decks	Chess piece patients, custom card decks for charts and records
Timing	Chests release blocks at measured rate	In-game Timers	In-game Timers
Variation	Coordination or lack thereof, human errors	Dice	Dice

Natural Experiments

The initial motivation for the virtual simulations were to provide an adequate educational experience for students during the pandemic. As part of the ongoing continuous improvement of the courses involved, data was collected that was used after the fact to compare outcomes and student satisfaction with the in-person simulations. There was not a deliberate experimental design. There was data on both student performance (in the form of grades) and student preferences and self-assessments (in the form of surveys) that could be used to directly compare the two modes.

In 2020 and 2021, the on-line simulations were used to teach process improvement and engineering courses at Northeastern (NEU), George Washington (GWU), and Loyola Marymount Los Angeles (LMU) universities. The on-line simulations were used exclusively in some cases; in others both on-line and in-person simulations were used. Table 3 summarizes the use of the simulations during this time. At LMU and GWU, data and experiences were also considered from some terms before and after the pandemic to provide a baseline of students using the in-person simulation; that was not necessary at NEU, where all terms were hybrid, with some students participating in the simulation remotely and others in person.

At NEU and LMU, students were surveyed at the end of each class. The survey was part of the final quiz and had an almost 100% return rate. Students were asked if the simulation "… help[s] you achieve the objectives of the course?" Students replied with a number -2 (strongly disagree) TO +2 (strongly agree). They were also asked "What features of the simulation experience did you find most useful for learning? The least? Rate the features below from 0 (not useful) to 5 (extremely useful)." The features are listed in Table 4. Student outcomes (final grades in the course) anonymously linked to which simulation was done by the student were also considered.

Table 3. Terms from which data was collected

Term	University	Mode	Number of Students	Graduate or Undergraduate	Simulations
Summer 2 2019	LMU	In-person	18	Graduate	Healthcare
Summer 2 2020	LMU	Remote	31	Graduate	Healthcare
Summer 2 2021	LMU	Remote	15	Graduate	Healthcare
Summer 2 2022	LMU	Hybrid	18	Graduate	Healthcare
Fall 2020	NEU	Hybrid	69	Both	Manufacturing, Product Development, Healthcare
Spring 2021	NEU	Hybrid	37	Both	Manufacturing, Product Development, Healthcare
Summer 1 2021	NEU	Hybrid	32	Both	Manufacturing, Product Development, Healthcare
Fall 2021	NEU	Hybrid	55	Both	Manufacturing, Product Development, Healthcare
Fall 2019	GWU	In-person	30	Undergraduate	Manufacturing
Fall 2020	GWU	Remote	24	Undergraduate	Manufacturing
Fall 2022	GWU	In-person	11	Undergraduate	Manufacturing

Table 4. Aspects of the simulation on student surveys

Did the [simulation] help you achieve the objectives of the course? (-2 to +2 Likert scale)
What features of the simulation experience did you find most useful for learning? (0 to 5 Likert scale)
Having fun playing the game
Seeing how processes behave in (simulated) reality
Thinking about and discussing improvements in unstructured time
Doing structured problem solving exercises (like the planning template)
Using lean tools TO IMPROVE the simulation process (like VSM, takt time, balance)
Using lean tools TO EXECUTE the simulation process (like visual control, kanban)
Getting a sense for how lean tools work in action
Understanding the need for enterprise lean
Understanding the need for multiple improvement iterations
Hearing supplemental lecture material
Hearing instructions on how to play the simulation
Interacting with fellow students
Learning to work as a team in the simulation

At GWU, the data consist of grades from three memos testing knowledge gained from the simulation, along with standard teaching evaluations. Grades were recorded for all students, while most but not all returned teaching evaluations. The three memos asked students to apply the knowledge gained from the simulation to suggest further improvements to the simulation's manufacturing setup and to analyze analogous real-world systems (such as "manufacturing" a burrito at a fast-food restaurant). As a result, the grades on this assignment assess how much they learned from the simulation directly. Two questions from the teaching evaluations are used: (1) how much was learned from the class (not specifically from the simulation) on a scale from 1 to 5, and a free-text question that asked what students enjoyed or did not enjoy about the class. The latter was quantified by counting the number of mentions of the simulation as an enjoyable aspect of the class.

LMU Results

Average answers to the question "Did the [simulation] help you achieve the objectives of the course?" separated by term and simulation mode are presented in Table 5. A grand average for in-person and remote sessions is also presented, with 95% confidence intervals calculated with a pooled standard deviation of 0.60. The students seem to prefer the in-person simulation, but the difference is not statistically significant. A one-way ANOVA test of the null hypothesis that the means are equal gives $p = 0.20$.

The questions about the specific features of the simulation experience also show a general trend favoring the in-person simulations. When tested for significance, most results are not significant. The two questions regarding "using lean tools TO IMPROVE the simulation process," and "using lean tools TO EXECUTE the simulation process" were exceptions; the results are shown below in Table 6. Student performance was also considered; the students who participated in the remote simulation actually received somewhat *better* final grades in the classes in which the simulations were used, but the result was not statistically significant.

Overall the results suggest that the students have a preference for the in-person simulations, but the results are not strong. It should also be noted that many of the remote sessions took place in the summer of 2020, when the results may have been confounded with other difficulties present at that time.

Table 5. LMU Results – Simulation helped achieve objectives?

Term	Mode	N	Average (max = 2)
Summer 2 2019	In-person	18	1.86
Summer 2 2020	Remote	31	1.65
Summer 2 2021	Remote	15	1.87
Summer 2 2022	In-person	12	1.92
Summer 2 2022	Remote	6	1.67
All	In-person	30	1.89 (1.67, 2.00)
	Remote	53	1.71 (1.54, 1.88)

Table 6. LMU Results – Simulation features with significantly different student responses

Mode	N	Average and CI (max = 5)	Means different? *p* value
using lean tools TO IMPROVE the simulation process			
In-person	31	4.77 (4.56, 4.99)	0.06
Remote	53	4.51 (4.34, 4.67)	
using lean tools TO EXECUTE the simulation process			
In-person	31	4.84 (4.61, 5.00)	0.02
Remote	53	4.32 (1.67, 4.66)	

NEU Results

The NEU results feature three different simulations being run in one or both modes, over four different terms. The collected results showed the same trend as the LMU results, with a higher level of significance. The student responses to the basic question of if the simulation helped achieve the course objectives are tabulated in Table 7 and shown graphically in Figure 5 below. The preference is not particularly strong (a difference of 0.18 on a -2 to +2 scale, or around 5% of the possible range of scores) but it is statistically significant.

Table 7. NEU results – simulation helped achieve objectives?

Mode	N	Average (max = 2)	95% CI	Means different? *p* value
In-person	119	1.84	(1.74, 1.95)	Yes 0.03
Remote	74	1.66	(1.53, 1.79)	

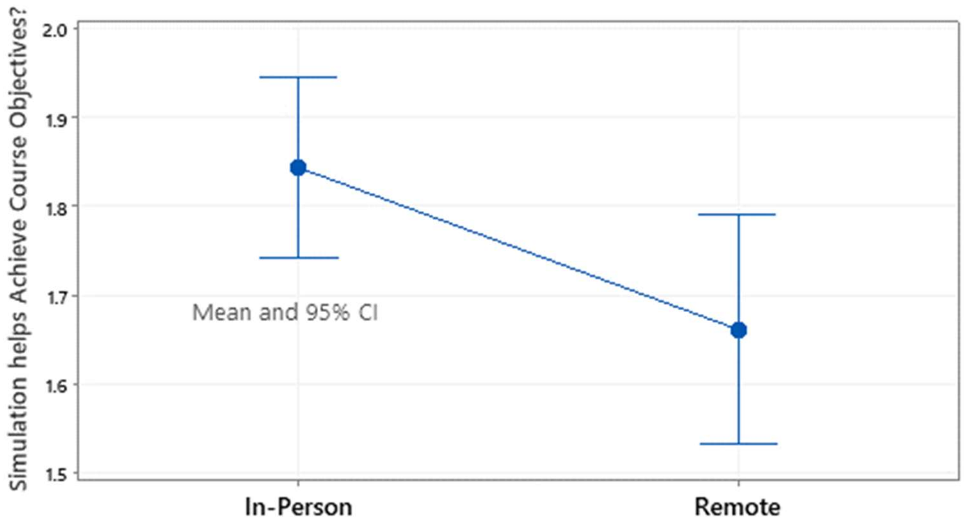

Figure 5. NEU results – simulation helped achieve course objectives?

The questions about individual simulation features yielded three distinct groups of results (see Table 7). There was no perceived difference in the usefulness of remote versus in-person simulations for having fun, discussing improvements, learning teamwork or getting a sense of how lean works. Other aspects such as seeing how simulation processes work, doing structured problem solving, interacting with other students, and understanding enterprise lean and the need for multiple improvement iterations were rated as more useful in the in-person simulation, but not by a significant amount. The use of lean tools for process improvement was rated significantly higher in the in-person simulations. Given that this is a main learning objective for the simulation, this is noteworthy result, and parallels the results seen at LMU.

Table 8. NEU results – simulation features useful for learning?

Simulation feature	Mean response in-person (n=119)	Mean response remote (n=72)	Means different? *p* value
Having fun playing the game	4.23	4.26	No 0.85
Seeing how processes behave in (simulated) reality	4.64	4.47	~ 0.20
Thinking about and discussing improvements in unstructured time	4.34	4.31	No 0.85
Doing structured problem solving exercises (like the planning template)	4.25	3.96	~ 0.11
Using lean tools TO IMPROVE the simulation process (like VSM, takt time, balance)	4.57	4.22	Yes 0.02
Using lean tools TO EXECUTE the simulation process (like visual control, kanban)	4.50	4.32	~ 0.22
Getting a sense for how lean tools work in action	4.36	4.39	No 0.85
Understanding the need for enterprise lean	4.09	3.82	~ 0.15
Understanding the need for multiple improvement iterations	4.37	4.17	~ 0.22
Hearing supplemental lecture material	3.53	3.57	No 0.84
Hearing instructions on how to play the simulation	4.10	4.08	No 0.95
Interacting with fellow students	4.26	4.03	~ 0.22
Learning to work as a team in the simulation	4.51	4.47	No 0.79

In an attempt to understand in more detail the responses of students to the different combinations of simulation mode and simulation type, a breakdown of the results shown in Figure 5 was carried out. Figure 6 shows the results separated by the simulation type. An important detail emerges; although the student response to the simulation was significantly lower for remote simulations overall, that difference did not apply to the manufacturing simulation. The remote manufacturing simulation was as highly rated as the in-person simulations, and rated higher than the other remote simulations. The manufacturing simulation is notably different from the other two, see Table 2. It is more immersive, with the students inhabiting avatars in a three-dimensional Minecraft world and building airplanes that appear (to the students) to life-sized. This gives some evidence for the idea that a more immersive simulation will more fully engage the students.

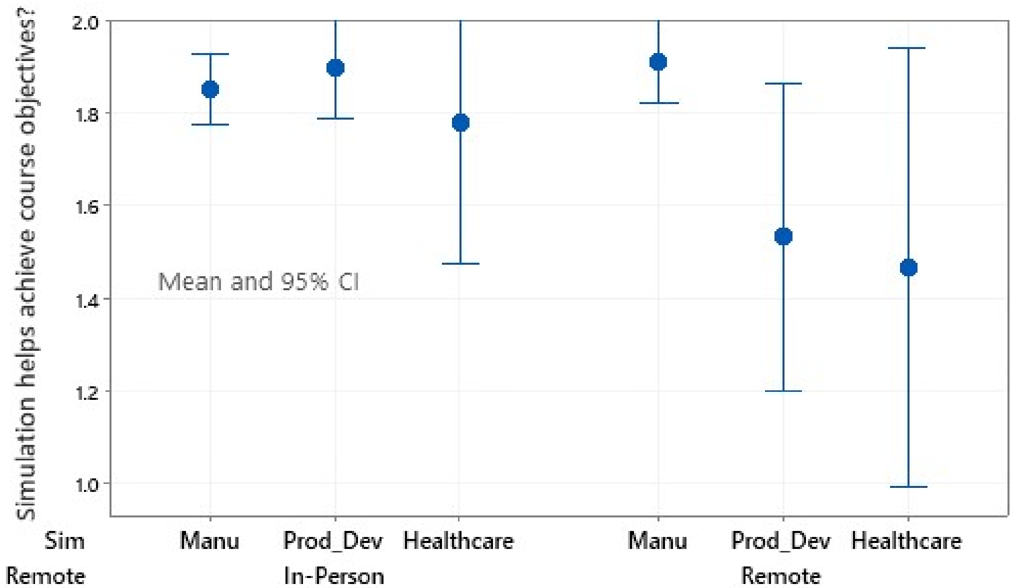

Figure 6. NEU simulation rating broken down by type of simulation

GWU Results

The GWU data show similar trends, although they are less useful for evaluating the specific details of the simulation, because the students were not asked the same survey question. However, the results reinforce similar trends. Table 9 shows results for three semesters: two in-person and one remote. The average score on the memo assignments, which assessed learning from the simulation, was roughly the same for Fall 2020 (remote) and Fall 2022 (in-person). It was different in Fall 2019 but used a different grading rubric, so these results are not easily comparable. This suggests that the in-person and remote methods achieved similar learning outcomes. The students in all three classes believed they learned similar amounts from the class as a whole, but this includes many other elements along with the simulation. Finally, to get a better understanding of how they perceived the simulation specifically, the responses to a free-text question about what they liked and disliked about the class were analyzed. Specifically, any responses that mentioned the simulation or phrases like "hands-on activities" were counted. All were positive. The results show that, for in-person classes, a higher percentage of the students

Table 9. GWU results

	No. Students	Avg. Score on Assignment	How Much Learned (entire class)	(Unsolicited) Comments, Normalized
In-person (Fall 2019)	30	0.97*	0.84	0.27
Remote (Fall 2020)	24	0.89	0.84	0.13
In-person (Fall 2022)	11	0.88	0.80	0.18

* a different grading rubric was used in Fall 2019, leading to different scores

wrote positively about the simulation than for the remote class. While these data are not conclusive, they reinforce the trends shown earlier, namely, that in-person simulations are somewhat more engaging to students than virtual ones, although learning and engagement occur in both cases.

Instructor Observations

The remote simulations were considerably easier to set up. They required no physical components to be laid out; they also required no rooms to be reserved and arranged. The latter is a major advantage. Reserving a 6-hour block of time on most university campuses is not an easy thing. This need often leads to having session on weekends or evenings, with negative effects on instructor and student work-life balance.

The remote simulations were, on the other hand, more difficult to facilitate. The most basic problem was they only allowed one group of 5-7 students to participate at one time (per facilitator), while the in-person sims can practically be run with up to 3 groups per facilitator and potentially just one professor for a larger number of groups. Surprisingly, most students were unfamiliar with the simulation software, even the popular Minecraft program, so some time was needed to train the students in the basics of the simulation environment before work on the actual simulation could start. Once things were running, it was more difficult to break away from the simulation environment. During in-person simulations, brainstorming exercise and set-ups in anticipation of active session could be done by the students relatively independently, allowing the instructors some time to prepare the next steps in the session. During remote simulations, the students often had questions specific to the simulation even in brainstorming sessions, and usually needed guidance during set-up exercises. With students in breakout rooms, it was therefore difficult for a facilitator to manage multiple groups. Being absent from the simulation even for a short time risked the possibility of "dead air" time. If the students perceived there was nothing going on in the simulation they were at risk of getting engaged in something in their real world or in other on-line environments. Once disengaged, it was harder to re-assemble the students than in a real-world classroom. Good on-line facilitation therefore required constant attention throughout the simulation period. Furthermore, some of the online simulation tools required solid internet connections and reasonable processing power. During the 2020 lockdowns, many students were at home, and some had limited internet bandwidth and fewer computing resources, so running Minecraft, google docs, and Zoom all at the same time was difficult.

Summary and Conclusions

On-line, virtual reality versions of several well-established in-person simulations were created during the pandemic using off-the-shelf software. Creation of these simulations allowed successful continuation of classes dependent on simulation-based learning during the Covid-19 pandemic. The simulations were perceived to be successful, but this was not at first quantified. Use of both the on-line and in-person versions of the simulations during classes at several universities, and consistent collection of survey data from the students, created a natural experiment in their relative effectiveness.

There was no significant difference in performance, as measured by their final grades in the class, between on-line and in-person simulation participants. The in-person versions of the simulations were consistently favored by the students in their assessments of whether the simulations advanced the learning objectives of the classes. This effect was not large (about 5% of the rating scale) but it was seen consistently across all studies, and shown to be statistically significant in the large NEU study. A set of survey questions on some of the details of the simulation experience produced mostly inconclusive results, except for a question on whether the simulation helped the students understand the use of lean tools to improve the simulation process. This question was answered significantly more favorably by students who did the in-person simulation. Given that learning to use lean tools is a major goal of the classes, this is consistent with the previous finding about advancing learning objectives.

An exception to the trend favoring in-person simulations was found in the manufacturing simulations, at least at NEU. The remote version of the manufacturing simulation was created in Minecraft, and immersed the students in a full-sized 3-D aircraft manufacturing facility. The students found this environment sufficiently engaging that there was no significant gap between the student evaluations of the Minecraft manufacturing simulation and the real-world LEGO one.

Although on-line simulations are significantly easier to set up and schedule, they do require more, and more intensive, facilitation. The on-line simulations can only handle a single group of 5-7 students at a time (per facilitator), and the students are fairly constantly dependent on instructor help to deal with the details of the simulated environment. The challenge then is clear – creating simulations that can handle more students, and are more robust and self-explanatory, so these students can act more independently in the simulated environment – and at the same time making the simulations as immersive and engaging as possible.

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