

# Priming Students for Risk Assessment in a Virtual Environment

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## ABSTRACT

Protecting worker health and safety is of utmost importance in the workplace. Identification of hazards and assessment of risk that those hazards present are critical in protecting employee health and safety. However, problems arise when these hazards are invisible and difficult to identify. Hazards like noise, radiation, and air quality are all invisible, yet can pose both acute and chronic health problems for workers.

AssessVR is a virtual reality simulator that facilitates student and safety worker learning on hazard identification and risk assessment. The simulator allows students to experience hazard recognition processes (e.g., noise, particles, and radiation), design evaluation strategy, and risk assessment and analysis using data output from the simulation.

Students used the AssessVR simulator in an Industrial Hygiene course at Iowa State University. The experiment process was a between-subjects design that included priming students in one of three settings: Utilitarian, Gamified, and Entertainment. Students then assessed the risk of noise exposure in a virtual machine room.

The quality of sound level probe placement (probe placement optimization score) by students was calculated in the simulation. Analysis demonstrated that students primed with the Gamified scene had significantly higher probe placement optimization scores than those primed in the Utilitarian scene. Students in the Gamified scene also had a significantly higher score on referencing noise exposure standards than the Utilitarian group. No significant differences were identified when compared to the Entertainment priming group.

## ABOUT THE AUTHORS

**Tavion Yrjo** is a graduate student at Iowa State University pursuing a degree in Human-Computer Interaction and co-majoring in Industrial and Agricultural Technology. Tavion received a B.S. in Software Engineering from Iowa State University in 2021. Tavion develops virtual reality simulations to supplement student and employee safety training with experiential learning endeavors.

**Nir Keren** is an Associate Professor of Occupational Safety at the Department of Agricultural (ABE) and Biosystems Engineering at Iowa State University and a Faculty Fellow at the Virtual Reality Application Center (VRAC), also at Iowa State University. Before pursuing an academic career, Nir was an engineer and a manager in the capital energy and process industries. In ABE at Iowa State University, Nir teaches Occupational Safety courses. In VRAC, Keren's interest in virtual reality is threefold: (1) Examining the decision-making of employees of mission-critical occupations under stress, (2) utilize virtual reality for improving safe design and engineering practices, and (3) utilizing virtual reality technology to enhance training transfer.

Nir received a Ph.D. in Interdisciplinary Engineering from Texas A&M University in 2003, an M.S. in Management and Safety Engineering from the Ben Gurion University in Israel in 1998, and a B.S. in Mechanical Engineering the Ben Gurion University in 1990.

**Andrew Lawson** is a Graphic Designer and VR Lab Manager at Iowa State University. Andrew received a B.A. in Graphic Design at Iowa State University in 2016. Andrew creates 3D models and graphics for use in simulations.

**Angela Leek** is a Certified Health Physicist and is currently the Radiation Control Program Director with the Iowa Department of Public Health. Angela has over 20 years of experience in the radiation safety and protection field and is currently a graduate student pursuing her Ph.D. in the Industrial and Agricultural Technology program within the Agricultural and Biosystems Engineering (ABE) Department at Iowa State University. Angela completed her M.S. in Radiation Health Physics at Oregon State University.

**Pete Evans** is an assistant professor in the Industrial Design department at Iowa State University with over 25 years of industry experience. Pete's teaching, scholarship and research involve mixed reality (VR and AR) simulation; digital communications, prototyping and design; impacts of 21st-century skills on K-16 students and workforce; UXUI, human computer interaction and human centered design; phenomenology and perceptual cognition. He also founded and coordinates the FLEx (Forward Learning Experience) - a mobile design & STEM outreach program.

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## BACKGROUND

Virtual reality has been identified as an effective training medium that is superior to traditional training techniques (Aggarwal et al., 2006; Cho et al., 2002; Kaplan et al., 2020). Aggarwal et al. (2006) demonstrated that VR technology can be used to effectively train inexperienced surgeons. Yang et al. (2008) exhibited that community ambulation in stroke victims was significantly improved with VR when compared to traditional treadmill training. Beyond physical skills, a significant number of references demonstrate that cognitive functions can be improved with VR (e.g., Maggio et al., 2019; Park et al., 2020; Shema-Shiratzky et al., 2018). Cognitive function improvements go beyond rehabilitation as well. Gamito et al. (2020) found improvements of cognitive function in elderly communities when administering VR based cognitive stimulation. Virtual reality training and simulations can also assist in decision-making skills (Pagé et al. 2019). Pagé et al. (2019) demonstrate that virtual reality-aided training led to transferable and generalizable gains in decision-making skills.

Virtual reality for safety training received significant attention. Leder et al. (2019) found immersive VR training to be comparable to a PowerPoint presentation in knowledge gain, but learners had significantly higher sense of presence. A study conducted by Škola et al. (2020) suggests that higher sense of presence leads to higher levels of engagement in the topic at hand. Puschmann et. al (2016) also found VR to be an effective medium for training learners on risk assessment and found assessment of risk to be comparable to other mediums. Another study found that the types of safety training reinforcement (positive or negative) may have an impact on peoples' risky behaviors in hazardous situations (Shi et al., 2019).

Engaging learners and the impact of engagement on learning have been studied extensively (e.g., Carini et al., 2006; Chi & Wylie, 2014, Strayhorn, 2008). Literature on the effects of serious games and digital game-based learning have suggested that gamifying learning can lead to increased engagement and enhanced learning outcomes (Anastasiadis, 2018; Checa & Bustillo, 2019). These studies showed that using a gaming approach improved knowledge gain, knowledge retention, and the development soft skills such as critical thinking, problem solving, and collaboration (Anastasiadis et al, 2018; Chittaro & Buttussi, 2015; Zhonggen, 2019). A meta-analysis conducted by Lamb et al. (2018) found that while serious games are comparable to traditional teaching methods, there are significant differences in learning outcomes and engagement between games with pedagogy components (serious educational games) and games with pedagogy added after the game was created (serious games).

The effects of cognitive priming for learners were significant in second-language learners (Kaan & Chun, 2017). However, there is a gap in understanding how priming learners using serious games or other game-based approaches affect the acquisition of risk assessment skills.

This study is an extension of a study titled Assessing Employee Risk due to Exposure to Hazards with a VR Simulator (Keren et al., 2021) that was presented and published in the proceedings of the 2021 IITSEC.

## METHODOLOGY

### The Simulation

A simulator (AssessVR) for PC desktops was created using the Unity game engine. The simulation consisted of three "priming" scenes and one final scene. The priming scenes were titled Utilitarian, Gamified, and Entertainment

(described below). Participants in the simulations were tasked with identifying sources of noise in the environment and assessing risk associated with these sources of noise. To traverse the environment, participants click on the ground to teleport to that position. Participants in the scenes had access to a sound level meter that displayed a live reading of the sound level (dBA) at the location of the probe. Participants could place the sound level probe at a distance. The probe functioned as a sound level meter that gave a live reading where placed. Probes could be deleted and replaced as many times as necessary. Participants were assigned a probe placement optimization score based on the number of probes placed, and the probes' location with respect to the noise sources. All scenes contained a site map to help guide participants to noise sources. The map was always accessible and had symbols marking the locations of noise sources, sound probes, and the participant. Participants could also save images of the map at any point by clicking on the "Save Map" button located next to the map (see figure 1 below). Following are descriptions of the priming scenes.

### Utilitarian Priming Scene

The Utilitarian priming scene is of a 'straight forward' machine room setting where noise sources emanated from various machines. Participants only had access to a map and the sound level meters, and they could place down only three sound probes. The scene contained six noise sources. Figure 1 presents a screenshot from the Utilitarian priming scene.

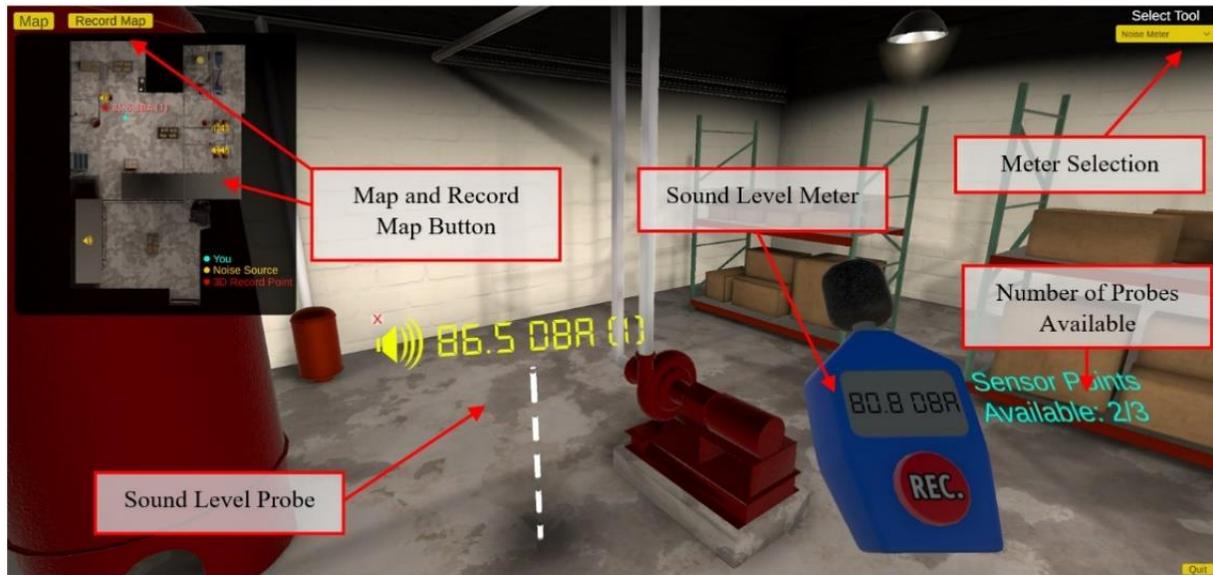


Figure 1. Utilitarian priming setting features

### Gamified Priming Scene

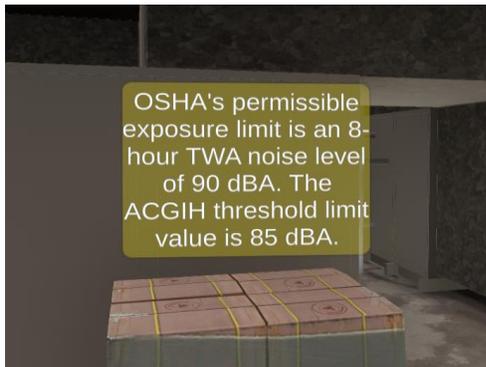
The Gamified scene consisted of the same machine room setting as the Utilitarian scene; however, in addition to the map and sound level meter, game elements were integrated into the simulation. Participants were told that they would receive a monetary reward that increased the higher they scored. The score was always visible to participants. Game elements included four hints that users could click on to acquire in-game money (\$100 each) and an in-game shop.

The money collected from hints could be used to purchase upgrades from the in-game shop. Three upgrades were available to participants: upgraded noise sensors (\$150), an enhanced map (\$250), and sound goggles (\$400). The purpose of the upgrades was to assist participants with effective placement of the sound probes. Participants could only place three sound probes at a time. The scene contained six noise sources. Figure 2 presents a screenshot from the Gamified priming scene.



**Figure 2. The Gamified priming setting features**

Figure 3 presents the interactable hint feature from the Gamified priming scene. Figure 4 presents a screenshot from the in-game shop.



**Figure 3. An interactable UI Hint**



**Figure 4. A page from the in-game shop**

### Entertainment Priming Scene

The Entertainment scene was a bar setting where noise sources were generated by speakers and arcade machines. The layout of the bar and locations of noise sources were similar to the Utilitarian and Gamified priming scenes. The type of sounds generated included music from the speakers and sound effects typically generated by arcade machines. Participants could only access the map and the sound level meter. They could place down only three sound probes at a time. The scene contains six noise sources. Figure 5 presents the Entertainment priming scene.

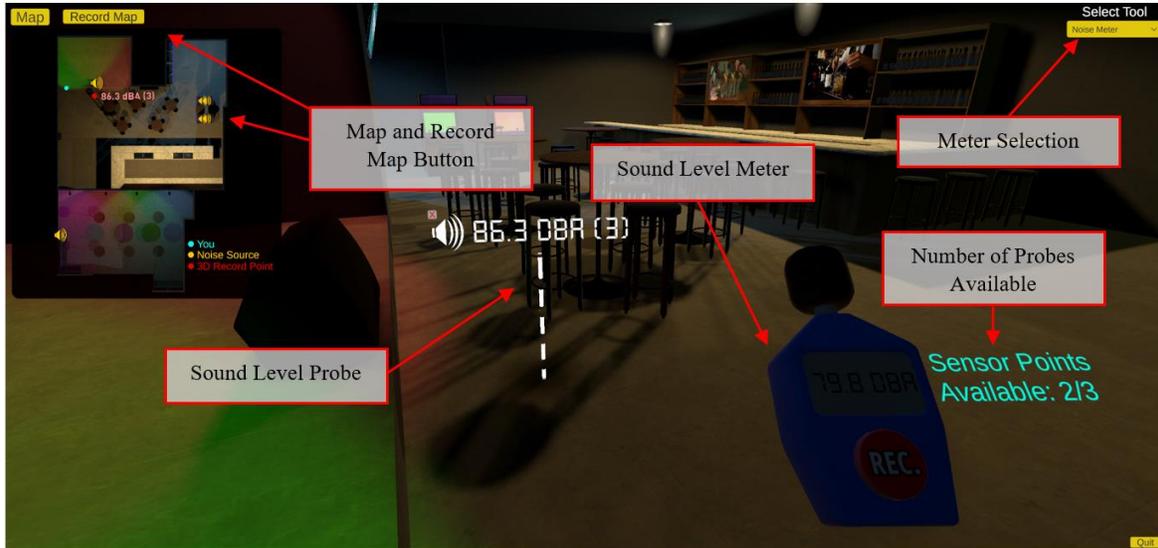


Figure 5. The Entertainment priming setting features

### Final Scene

The final scene was the same machine room environment as the Utilitarian and Gamified settings. However, different noise sources were introduced, and the location of noise sources were changed. Participants had access to the map and the sound level meter, and could place up to 99 sound level probes.



Figure 6. The final machine room scene

### Post Simulation Tasks

After completing the priming simulation, participants were asked to fill a Presence Questionnaire (SUS) (Usou et al., 2000) and a modified version of the Gameful Experience Questionnaire (GEQ). Upon completing the questionnaires participants were asked to engage in the final scene. Finally, participants had to write an analysis report for the noise hazard/risk in the final scene.

The Presence questionnaire consisted of six questions that represent the following three aspects:

1. **“Being there”**: The sensation of “being” in the virtual environment.
2. **“Dominance of virtual environment vs. dominance of reality”**: The extent to which the virtual environment becomes the dominant reality over the real world.
3. **“VR experience as a place or an image/multimedia”**: The extent to which the virtual environment experience is remembered as a place visited in the real world rather than an image seen or other multimedia format.

Participants rated their level of agreement with the Presence items on a 7-point Likert scale. Table 1 presents the Presence questionnaire.

**Table 1. The SUS Presence Questionnaire and its relevant aspects.**

Code	Question	Presence Aspect
Q1	I had a sense of “being there” in the machine room... (1) Not at all... (7) Very much.	Being there
Q2	There were times during the experience when the machine room was the reality for me... (1) At no time... (7) Almost all the time.	Dominance of virtual environment vs dominance of reality
Q3	The machine room seems to me to be more like... (1) Images that I saw... (7) Somewhere that I visited.	VR experience as a place or as an image/multimedia
Q4	I had a stronger sense of... (1) Being elsewhere... (7) Being in the machine room.	Being there
Q5	I think of the machine room as a place in a way similar to other places that I’ve been today... (1) Not at all... (7) Very much so.	Dominance of virtual environment vs. dominance of reality
Q6	During the experience I often thought that I was really standing in the machine room... (1) Not very often... (7) Very much so.	VR experience as a place or image/multimedia

The GEQ is a measure of the participant’s experience on the following aspects:

1. **Competence**: The feeling that participants can do a task successfully or efficiently.
2. **Sensory and Imaginative Immersion**: The extent of immersion in the simulation.
3. **Flow**: The extent to which the participant is absorbed in the simulation.
4. **Tension/Annoyance**: The extent to which the participant feels irritated or annoyed
5. **Challenge**: The extent to which the simulation challenged participants competencies.
6. **Negative Affect**: The extent to which participants felt negative emotions towards the simulation.
7. **Positive Affect**: The extent to which participants felt positive emotions towards the simulation.

GEQ item ratings were on a 5-point Likert scale (0 - Not at all, 1 - Slightly, 2 - Moderately, 3 - Fairly, 4 - Extremely). Table 2 presents the modified GEQ.

**Table 2. The Gameful Experience Questionnaire and its relevant aspects.**

Code	Question	Gameful Aspect
Q1	I felt content	Positive Affect
Q2	I felt skillful	Competence
Q3	I thought it was fun	Positive Affect
Q4	I was fully occupied with the game	Flow
Q5	I felt happy	Positive Affect
Q6	It gave me a bad mood	Negative Affect
Q7	I thought about other things	Negative Affect
Q8	I found it tiresome	Negative Affect
Q9	It was aesthetically pleasing	Sensory and Imaginative Immersion
Q10	I felt good	Positive Affect
Q11	I felt bored	Negative Affect
Q12	I felt imaginative	Sensory and Imaginative Immersion
Q13	I felt annoyed	Tension/Annoyance
Q14	I felt pressured	Challenge
Q15	I felt irritable	Tension/Annoyance
Q16	I found it impressive	Sensory and Imaginative Immersion

## Written Analysis

The written analysis was evaluated using the following five dimensions: hazard identification, reference to exposure standards, exposure assessment, strategic approach, and control recommendations. Scores for each of these criteria, except for control recommendations, were on the following scale: weak (one point), moderate (two points), and strong (three points). Further, probe placement optimization is evaluated (described later).

### Hazard Identification

If a participant did not mention any noise sources, they received a weak score (1 point). If they only identified some noise sources, they received a moderate score (2 points). If a participant explicitly identified all noise sources in their analysis, then they received a strong score (3 points).

### Reference to Exposure Standards

If a participant did not mention any standards or only referenced standards by name, then they received a weak score (1 point). If a participant mentioned either the action level<sup>1</sup> (AL) or permissible exposure limits<sup>2</sup> (PEL), they received a moderate score (2 points). If a participant referenced both the action level and permissible exposure limits, they received a strong score (3 points).

### Exposure Assessment

If a participant did not make any assessment of occupational noise hazards, they received a weak score (1 point). If a participant provided a general assessment of the hazard (e.g., “the environment is above 85 decibels which requires the inclusion of a hearing conservation program”), they received a moderate score (2 points). If a participant calculated the Time Weighted Average values, they received a strong score (3 points).

### Strategic Approach

If a participant did not demonstrate a strategic approach, or randomly wandered around the environment, then they received a weak score (1 point). If a participant mentioned some strategic reasoning for their movement and measurement locations, they received a moderate score (2 points). If a participant had a clear and defined strategy for assessing the environment, they received a strong score (3 points).

### Control Recommendations

Additional control recommendations proposed by the students were scored additively on the following scale: Administrative or personal protective equipment (PPE) recommendations received one point each, safety features received two points each, engineering controls received three points each, and elimination controls received four points each.

## RESULTS

Due to low sample size, all statistical documentations were nonparametric.

### Reference to Exposure Standards

Table 3 presents the means and standard deviations for *Reference to Exposure* evaluations for each priming setting.

**Table 3. Means and Standard Deviations for Reference to Exposure Standards evaluation**

Priming Setting	n	Mean	Standard Deviation
Utilitarian	7	1.71	0.49
Entertainment	6	2.00	0.63
Gamified	7	2.57	0.54

<sup>1</sup> 29 CFR 1910.95(c)(2)

<sup>2</sup> 29 CFR 1910.95(b)(2)

A Kruskal-Wallis test was conducted for assessing overall statistical differences among the group settings. Results demonstrated that the differences were significant  $\chi^2(2, 20) = 6.6110, p = .0367$ . Table 4 presents nonparametric comparisons for each pair of priming settings using the Wilcoxon Method.

**Table 4. Nonparametric comparisons of Reference to Exposure Standards evaluation for each pair of priming settings**

Setting 1	Setting 2	Z	p-Value
Gamified	Entertainment	1.52574	.1271
Utilitarian	Entertainment	-0.79170	.4285
Utilitarian	Gamified	-2.37020	.0178*

Significance criteria:  $\alpha=.05$

Nonparametric comparisons for each pair of priming settings using the Wilcoxon Method demonstrated that reference to exposure standards was significantly higher in the Gamified setting in comparison to the Utilitarian setting,  $p = .0178$ , and the effect size was large,  $d = 1.67$ . No other significances were detected.

**Probe Placement Optimization Scores**

Table 5 presents the means and standard deviations for *Probe Placement Optimization Scores* for each priming setting.

**Table 5. Means and Standard Deviations for Probe Placement Optimization Scores**

Priming Setting	n	Mean	Standard Deviation
Utilitarian	5	0.036	0.04
Entertainment	5	0.116	0.11
Gamified	4	0.150	0.12

A Kruskal-Wallis test was conducted for overall statistical differences among the group settings. Results demonstrated that the differences on the overall model were not significant. However, a nonparametric comparison for each pair of priming settings using the Wilcoxon Method demonstrated the probe placement optimization score in the Gamified setting was significantly higher than the score in the Utilitarian setting,  $p = .0481$ , and the effect size was large,  $d = 1.28$ . Table 6 presents nonparametric comparisons for each pair of priming settings using the Wilcoxon Method.

**Table 6. Nonparametric comparisons of Probe Placement Optimization Score for each pair of priming settings**

Setting 1	Setting 2	Z	p-Value
Gamified	Entertainment	0.36742	.7133
Utilitarian	Entertainment	-1.15594	.2477
Utilitarian	Gamified	-1.97613	.0481*

Significance criteria:  $\alpha=.05$

There were no significant differences between priming settings for the Presence Questionnaire and Gameful Experience Questionnaire.

**DISCUSSION**

The effects of priming learners for performing complex tasks such as risk assessment by utilizing serious game-based learning techniques received little attention. The study herein examined the effects of different priming settings on knowledge gain and risk assessment in participants studying occupational hearing loss. Student achievements were assessed on the following six dimensions: Probe placement optimization score, hazard identification, reference to exposure standards, exposure assessments, strategic approach, and control recommendations. The analyses identified

that priming with the Gamified setting yielded significantly higher reference to exposure standards in comparison to the Utilitarian priming settings. Similarly, probe placement optimization scores were significantly higher in the Gamified setting in comparison to the Utilitarian priming setting. Effect size in both dimensions was large. There were no significant differences among the priming groups on the hazard identification, exposure assessments, strategic approach, and control recommendations evaluation dimensions.

The greater reference to exposure standards witnessed in the Gamified setting is interesting because it shows a transfer of knowledge from the in-game hints that were provided during priming to their analysis of a different environment (the final scene). Additionally, the probe placement optimization scores for participants primed with the Gamified setting were likely higher than the Utilitarian because participants were able to see their score in the priming setting. However, the probe placement optimization score was relatively low in all priming groups. Allowing participants in the final scene to place up to 99 sound probes was probably a major contributing factor to the low probe placement optimization scores.

Certain literature has suggested that Entertainment can lead to enhanced learning outcomes (Choi, 2018); however, that was not witnessed in this study. The low sample size was also a concern with this study as six students did not submit any simulation data to analyze, and three students did not submit an analysis report.

The increased performance, on certain task aspects, in the Gamified setting is consistent with literature surrounding serious games as a potential medium for educating learners. It should be noted that participants in the Gamified setting referenced specific in-game hints in their analyses as contributing factors to their learning achievements. While small, the effects of the different priming settings on accomplishments in this study are observable, hinting at the potential of Gamified priming settings for enhancing risk assessment skills. Further examination is needed to explain the lack of significant differences in the other four evaluation dimensions. The following efforts in this line of research will focus on developing other in-game features, similar to the 'hints' feature, that will aim at improving performance in the other four evaluation dimensions. Finally, no significant differences in the level of presence were identified among the three-priming settings.

## LIMITATIONS

The simulator was only available as a PC application. The impact of conducting the study in a full-scale VR mode in a VR headset should be evaluated.

For the Entertainment priming setting, it is unclear to what extent the setting provided herein facilitates entertainment. Copyright and simulation engine limitations hindered incorporating elements such as YouTube videos that the authors believe could carry higher entertainment merit.

Finally, the participants in this study were students from the Industrial Hygiene class at Iowa State University, which was offered as an asynchronous, online mode. The class consisted of 24 students. Six of the students did not submit in-simulation data, and three students did not submit an analysis of the environment. A larger cohort study may yield more observable results.

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