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# Enhancing risk assessment skills in hazardous environments: Priming with a serious game approach

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A B S T R A C T

Occupational risk assessments, critical for identifying hazards such as noise, radiation, and air quality, are challenging due to their complex and often invisible nature. In response, we developed AssessVR, a serious game-based simulation tool, designed to enhance risk assessment skills among students and safety professionals.

This study included twenty-seven students from three US universities, all of whom had completed a module on Occupational Hearing Loss and risk assessment in an Industrial Hygiene course. These students were assigned to either the Utilitarian or Gamified version of AssessVR for a risk assessment case study.

The results indicated that students using the Gamified version of AssessVR tended to perform better in specific risk assessment areas, such as *Exposure Assessment* and *Reference to Exposure Standards*. However, this improvement was not uniform across all evaluation metrics.

These findings suggest that while AssessVR, particularly its Gamified form, has potential in risk assessment skill acquisition, its effectiveness varies across different assessment areas. This underscores the need for further research and development in serious game-based simulations to optimize their role in enhancing occupational hazards management competencies.

## 1. Introduction

Risk assessment in the workplace is a crucial element of operational management, necessitating comprehensive competencies in identifying, evaluating, and mitigating hazards. The challenge of effective risk assessment stems from the need to consider diverse hazards—ranging from physical, chemical, to ergonomic—and adapt to the unique susceptibilities of various worker groups. In addition to this, the evolving legal landscape and the incorporation of new monitoring and prevention technologies add layers of complexity. This study focuses on enhancing risk assessment competencies, emphasizing the importance of proactive and adaptive approaches to manage noise-related risks, which, though less visible, can have significant long-term health impacts.

In the pursuit of improved risk assessment strategies, this study explores the role of innovative training methods, particularly serious games combined with priming strategies, to enhance risk assessment learning and competency. Serious games, offering contextually relevant, experiential learning opportunities, align closely with the needs of effective hazard recognition and risk assessment in complex environments like noise exposure. Priming, as a cognitive preparatory technique, can further reinforce the impact of these interactive learning tools. This integrated approach aims to cultivate and refine risk assessment skills, stepping beyond traditional, less engaging training methodologies. The key objective of this study is to explore the impact of a serious game designed for assessment of noise exposure risk in conjunction of priming procedure on risk assessment learning and competency acquisition.

## 2. Literature review

### 2.1. Risk assessment

Risk assessment of workplace hazards is a multifaceted aspect of operational management, encompassing the systematic identification of potential hazards, evaluation of associated risks, and the implementation of appropriate control measures. This complexity arises from the need to consider a wide range of factors such as the diversity of potential hazards—physical, chemical, biological, and ergonomic—the varying susceptibilities of different workers, evolving legal regulations, and the integration of new technologies for monitoring and prevention. Effective risk management thus requires a multidisciplinary approach that is adaptive to the unique dynamics of each workplace. Each workplace is

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unique, encompassing different sets of hazards and potential risks. Thus, a risk assessment strategy that works in one setting might be unsuitable in another. This variance necessitates a flexible and context-specific approach, which can be difficult to establish and manage.

Despite its criticality, conducting a thorough risk assessment is beset by several challenges, leading to complexities and potential shortcomings. A substantial body of literature documented these complexities (e.g., Ale et al., 2008; Jensen et al., 2022; Main, 2004; Rausand, 2011).

Identification of hazards is the first step in risk assessment and can be particularly challenging. Hallowell and Hansen (2016) have expounded upon the difficulties faced by workers when attempting to pinpoint potential hazards, particularly during the design phase of projects. This challenge is not limited to a specific category of workers, as both experienced and inexperienced individuals encounter obstacles in recognizing both existing and emerging hazards (Bahn, 2013). Invisible hazards such as poor air quality, stress, or noise pollution may also go unnoticed, as these hazards are difficult to detect without proper training or equipment. Training has proven effective in increasing worker's awareness of hazards (Hallowell & Hansen, 2016; Liang et al., 2019; Marahatta et al., 2018; Robson et al., 2012).

Traditional methods of safety training, such as lectures, slideshows, videos, and images, have long been employed; however, they often face difficulties in maintaining learners' attention and fostering meaningful engagement, as observed by previous studies (Clarke & Ward, 2006; Gao et al., 2019; Watkins & Corry, 2008). To address these challenges and improve workers' hazard identification skills, novel training approaches have emerged. Many of these approaches include the utilization of immersive technologies like virtual reality and augmented reality (Checa & Bustillo, 2019; Chittaro & Buttussi, 2015; Feng et al., 2020; Moore et al., 2019), as well as the implementation of gamification techniques (Dzeng et al., 2015; Liang et al., 2019; Mohd et al., 2019). The overarching aim of these innovative methods is to evoke heightened learner engagement and motivation, ultimately resulting in more effective learning outcomes, aligning with research by Anastasiadis (2018), Checa and Bustillo (2019), and Chi and Wylie (2014).

Risk quantification, which determines the severity of the risk, adds substantial complexity. The subjective nature of quantifying risks and the unpredictability of events can lead to significant discrepancies and under or over-risk estimations. For example, Prince et al. (1997) analyzed data from a survey on occupational noise and hearing. The study focused on the risk of hearing problems in relation to age, duration of exposure, and noise levels at work. The analysis considered different factors, such as the shape of the dose–response curve and the noise exposure among low-noise workers. The results revealed that the risk estimates varied depending on statistical models and assumptions. The choice of hearing frequency also influenced the risk estimates, which were affected by age and duration of exposure. Pega and colleagues (2020) reported that, among others, exposure misclassifications, incomplete exposure data, and selective reporting are substantial risk assessment biasing factors.

Risk assessment often requires the expertise of several parties, including safety professionals, health experts, management, and the workforce. Coordination among these diverse parties to gather accurate information, assess it, and decide upon control measures can be intricate and time-consuming.

Amid these challenges, ensuring compliance with various regulations is paramount. These regulations often evolve to reflect the changing nature of work and associated hazards, requiring vigilance and responsiveness. Non-compliance, either due to ignorance or oversight, could result in penalties and, more concerning, an increased risk.

Even when risk assessment processes are well-established, maintaining their efficiency over time is a constant challenge. Changes in business operations, workforce composition, legislation, and even the physical workplace can render a once-effective risk assessment obsolete. Regular review and updating of risk assessment processes, although essential, can be resource-intensive and complex.

In conclusion, risk assessment is an indispensable part of workplace safety, and its execution involves numerous intricacies and difficulties. Therefore, safety personnel with proper risk assessment skills are critical. When the safety personnel are risk assessment capable, an effective proactive approach to tackling the challenges associated with risk assessment will ensure a safe and productive work environment.

### 2.2. *Training for risk assessment skill acquisition*

Surprisingly, limited research exists on risk assessment competence acquisition. Hsieh et al. (2010) conducted a study that sought to identify essential core competences for Industrial Safety and Health Professional Engineers (ISHPEs), evaluate their current levels of proficiency as perceived by Safety and Health Managers. They identified seven core competences and 35 sub-core competences. Field surveys revealed a deficiency in core competences among ISHPEs, with basic safety and health skills, safety and health strategy/program conducting, management and financial planning, and leadership and systemic thinking skills identified as the top areas needing improvement. The conclude that there is a clear need for enhanced training in key competency areas for ISHPEs.

Thabit and Younus (2018) addresses the prevalence of accidents in the construction industry in Iraq and emphasizes the need for effective measures to enhance safety on construction sites, covering various project types from small houses to large buildings. They emphasize the necessity of thorough training and enforcement of stringent policies to manage workplace risks effectively.

Cerezo-Narváez et al. (2019) presents a case study on the effectiveness of the Lego® Serious Play® (LSP) method for teaching industrial risk prevention competencies to engineering students in Spain. The LSP approach involved gamified activities such as risk assessments and safety inspections, integrating both specific variables like industrial sector knowledge and broader skills like leadership and communication. Through this method, students could practically apply theoretical knowledge to identify risks, analyze solutions, and make decisions in a dynamic and engaging learning environment, ultimately expected to enhance their motivation and proactive engagement in occupational safety and health.

### 2.3. *Learning, serious Games, and priming*

Video games are widely recognized as engaging and entertaining (Picton et al., 2020). Literature has shown that video games have significant added merit. Video games have been implemented to promote workforce development for more than 25 years (e.g., Breuer & Bente, 2010; Checa & Bustillo, 2019; Chittaro & Buttussi, 2015; Lieberman & Brown, 1995; Susi et al., 2007; Zhonggen, 2019).

The term "serious games" was first introduced by Abt (1987) to describe video games designed specifically for training and education. Since then, serious games have rapidly grown in popularity and have been applied in numerous areas; for example, serious games are in the service of training healthcare professionals (Wang et al., 2016) and educating civilians about the US military (Zyda, 2005). Safety training is another area where serious games have substantial potential to improve knowledge retention and skill development (Kazar & Comu, 2021). For instance, a virtual reality serious game was developed to enhance aviation safety knowledge and was more effective than traditional safety card training, evoking higher levels of fear and engagement (Chittaro & Buttussi, 2015). Likewise, immersive virtual reality serious games have been used to enhance earthquake training. Feng et al. (2020) created a simulation to improve child safety during earthquakes; their results demonstrated that the virtual reality approach was more effective than traditional leaflet-based training. Liang et al. (2019) report that serious games can enhance essential aspects of risk assessment skills, such as hazard recognition.

Serious games' ability to increase player engagement has substantial merit. Dawood et al. (2014) demonstrated that 4D serious games improved user engagement and the ability to identify hazards. It is important to note that literature consists of various definitions for engagement as it relates to serious games. Axelson and Flick (2010) describe engagement as the extent to which students are involved and interested in their learning and their connection to their school and peers. Fox et al. (2009) define engagement as the level of involvement in a specific activity. Horrey et al. (2017) explain task engagement as an individual's personal investment, interest, and motivation to perform a task, regardless of difficulty. Dicheva et al. (2015) define engagement as the degree of attention, curiosity, interest, and passion students exhibit during learning, extending to their motivation to learn and progress in their education. Conversely, Hamari et al. (2016) argue that the multi-faceted construct of engagement in serious games encompasses behavioral, emotional, and cognitive aspects of user interaction; factors such as concentration, interest, enjoyment, and effort are also considered.

These definition differences can impact the assessment and the design of learning with video games. For instance, Dichev and Dicheva (2017) reported a positive association between student level of interaction with games and learning outcomes. On the other hand, Hamari et al. (2016) found that while engagement characteristics, such as time spent on the game, were associated with enhanced learning outcomes, emotional engagement (e.g., enjoyment) was not necessarily indicative of learning.

Similarly, Dichev and Dicheva (2017) highlighted the role of individual differences in shaping engagement and learning outcomes; they suggest that serious games should be tailored to learners' individual needs and preferences. Hamari et al. (2016) supported this claim; they found that the effectiveness of serious games as learning tools depends on the alignment between the game design and the learner's characteristics.

Therefore, examining the merit of implementing relevant learning theories in the design and execution of serious games is crucial for proper game development. For learning theories, Cognitive Load Theory (CLT) focuses on modifying and reducing the mental effort required for an activity (Sweller, 1994). According to Sweller, teaching learners anything more than acquiring and automating schemas can lead to a higher cognitive load and ineffective instruction. Constructivism is another popular learning theory that emphasizes learners constructing knowledge and meaning (Hein, 1991). When learners encounter new experiences, it is essential to allow them to reflect on the experience, ask questions, and explore their prior knowledge to adjust their beliefs (Bada & Olusegun, 2015). Based on the Experiential Learning Theory (ELT), the best way to learn is through hands-on experiences (Kolb, 1984). ELT involves four stages of learning: concrete experience, where learners are exposed to new experiences or interpret past experiences in new ways; reflective observation, where learners reflect on their experiences to understand their meaning; abstract conceptualization, where learners form new ideas or adjust their thinking; and active experimentation, where learners apply new ideas to the world around them (McCarthy, 2010; Western Governors University, 2020). Experiential opportunities are crucial for learning as they minimize cognitive load and facilitate reflection, leveraging the benefits of these learning theories. Serious games offer a way to create contextually relevant experiential opportunities that can vary in difficulty to adapt to individual learner needs.

Recent literature emphasizes the significance of integrating specific learning theories into serious game design to ensure their educational efficacy. Engagement in serious games is a complex construct that encompasses behavioral, emotional, and cognitive aspects. Recent studies have investigated the multifaceted nature of engagement and its impact on learning outcomes within serious games (Hamari et al., 2020). Game-Based Learning (GBL) theories have been refined to highlight the importance of aligning game mechanics with educational content to promote learning through action and reflection within the game environment (Krath et al., 2021). Csikszentmihalyi's Flow theory (1975) has been further explored in the context of serious games, suggesting that the balance between challenge and skill is crucial in maintaining engagement and facilitating deep learning (e.g., Buzady et al., 2022). Self-Determination Theory (SDT) has been applied to serious games to enhance motivation by satisfying the player's need for autonomy, competence, and relatedness, thus leading to better learning outcomes (Przybylski et al., 2020). The ARCS model (Attention, Relevance, Confidence, and Satisfaction) of motivational design also remains a cornerstone in designing educational games, ensuring they capture attention, are perceived as relevant, increase learner confidence, and provide satisfaction (e.g., Konstantinidou & Nisiforou, 2021; Hao & Lee, 2021).

Krath et al. (2021) conducted a systematic review of gamification and serious Games-based learning theories. Their analysis yielded relevant 118 theories that were used to explain gamification-relevant learning. Their results indicate that Self-determination (Deci & Ryan, 1985), Flow (Csikszentmihalyi, 1975), Experiential Learning (Kolb, 1984), and Constructivist learning (Jonassen, 1999; Piaget, 1977) are the most popular theories. Krath et al. (2021), identified ten principles that can assist with understanding how gamification leads to the desired goals and the relevant theories. They further identified three themes that encompass these principles, namely, 'Principles that guide towards the intended behavioral outcomes,' 'Principles that foster individual relevance,' and 'Principles that enable social interaction and positive social effects' (p. 14).

Literature provides that priming learners before they engage in learning carries merit in enhancing learning outcomes. One form of priming involves providing preliminary information before introducing new content. Successful knowledge transfer requires connecting new knowledge to relevant contexts purposefully and reflectively (Roumell, 2019). Priming can also help identify and address learners' misconceptions when they encounter experiences that contradict their prior knowledge (Kalyuga and Singh, 2016). Wexler et al. (2016) demonstrated that using brain training games before learning math or reading curricular games improved performance in those games and led to enhanced math and reading achievements among second-grade children (Wexler et al., 2016). In Constructivism, language plays a crucial role in learning, as it can influence learning outcomes. Lexical priming research supports the idea that speakers are more likely to repeat language structures they have recently heard (Jackson, 2017). A substantial body of literature addressed priming in serious games. Cheng et al. (2023) report that learning objectives were better-understood post-priming, leading to increased engagement and improved learning outcomes. Priming can also reduce cognitive load resulting in an enhanced focus on the material when using games for learning (Hainey et al., 2023). Furthermore, de Freitas (2023) proposes that proper priming would increase learning motivation, enhancing learner engagement and learning outcomes. Consequently, incorporating priming strategies when designing serious games can carry merit.

As has been established above, risk assessment skills are essential for safety personnel; yet risk assessment is complex. It is often more complex when the hazards are invisible, such as with noise hazards. In parallel, serious games are used in workforce development endeavors, including training for assessing and managing workplace risks such as violence (Mason and Loader, 2019). Leek et al. (2023) report that priming learners with alarming words before they engaged in a simulation for assessing a radiation incident led to a significantly higher perception that working in the radiation environment was manageable compared to the perception among learners primed with non-alarming words. Yrjo et al. (2022) conducted a study on whether priming learners prior to engaging in risk assessment tasks led to slightly improved risk assessment skills. The results from this study pointed to the need to focus on gamification features to provide a robust bed for risk assessment skill development. The study herein presents the impact of enhancing the priming in Yrjo's approach (2022) with gamified features on the quality of risk assessment of hazardous noise in the workplace. A non-gamified version of the serious game was used to benchmark the results from the gamified version.

## 3. Methodology

### 3.1. Experimental design

Industrial hygiene courses introduce Occupational Hearing Loss modules. The material introduced in these modules spans from the nature of sound, through the human physiology of hearing, to anticipating, recognizing, evaluating, and controlling noise levels in workplaces. A non-immersive virtual reality simulation titled AssessVR was developed to supplement the Occupational Hearing Loss module by providing a constructively engaging learning experience.

Twenty-seven seniors and graduate students from three universities who took an industrial hygiene course participated in the study. All students in the three institutions were provided with the same foundational information and completed a learning module on Occupational Hearing Loss as part of the Industrial Hygiene course.

The students were divided into two groups. The selection for each group was also randomized to further ensure consistency and minimize any potential impact on the study results due to any unforeseen differences in information exposure.

One group was assigned to a Gamified priming setting of AssessVR (the Gamified group) and the other to a Utilitarian setting (the Utilitarian group), as described below. Students were asked to use output from the simulation to write a summary risk assessment report. As mentioned earlier, the Utilitarian group results were used as a benchmark for the results from the Gamified group. The working hypothesis was that risk assessment quality of students in the Gamified Group would be enhanced compared to the risk assessment quality of students in the Utilitarian group. The study was reviewed and deemed exempt by the Iowa State University Institutional Review Board (Study 21–149). Fig. 1 presents the experimental design.

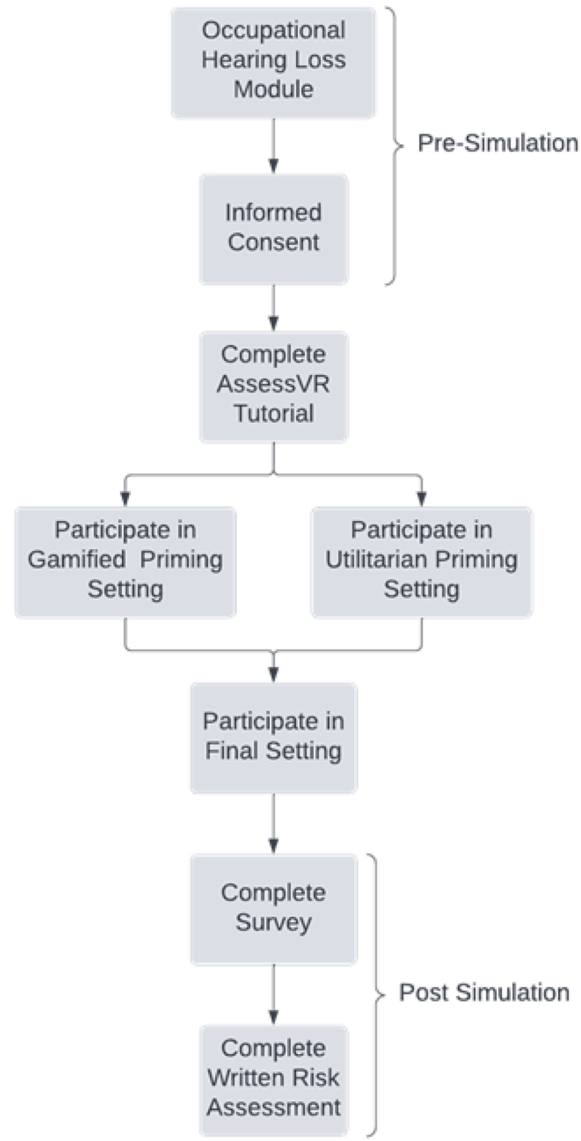


**Fig. 1.** Experimental design.

### 3.2. The AssessVR simulator

When engaged in AssessVR, students could explore a virtual machine-room environment to assess the noise level. Students could navigate the environment by clicking on the floor to instantly teleport to that location. During the simulation, the users carried a sound-level meter that provided live readings of the noise level in decibels (dBA) (see Fig. 2). Students could also place noise level probes, which acted as stationary noise level meters at any location in the machine room. Each student received a probe placement optimization score based on the positioning of the noise level probes relative to the noise sources. Students from each group were asked to examine the virtual machine-room and experience using the noise level meter and placing noise probes. Live readings from the probes were visible at the probe locations (see Fig. 2). Sound was generated by various sources of noise (e.g., pumps, remote terminal units, generators, etc.) in the environment. The level of noise from these sources fluctuated throughout the workday. While in the simulation, students could change the time of day to observe noise levels at each hour during the workday.

To facilitate noise level measurements at any point in the machine room, the noise level from each source was calculated based on the distance from the source. The sum of the noise levels, from all sources, was displayed on student's noise level meters. Noise level at distance $d$ from a noise source was calculated with Equation (1), where $dB_{at\ a\ distance\ d}$ is the noise level at $d$ feet from the noise source:

$$dB_{at\ distanced} = dB_{at\ source} - 20 \times \log(d) + 2.5 \times dB \tag{1}$$

The combined noise level of several sources was calculated with Equation (2), where $dB_{sum}$ is the combined noise level at a point, $L_i$ is the noise level from source $i$ at the measurement point, and $n$ is the number of noise sources:

$$dB_{sum} = \sum_{i=1}^{n} 10^{\frac{L_i}{10}} \tag{2}$$

No other factors affecting noise levels, such as barriers, noise absorption, reflection, and reverberation, have been incorporated into the noise level calculations.

To aid students in locating noise sources, a site map was available in all settings, and students had the option to export map images to their personal computers by clicking the "Record Map" button (see Fig. 2).

Students were given an objective statement at the beginning of the simulation, and they could access it at any time by clicking the "Tips" button (see Fig. 3).

To improve usability, a thorough "Help" menu was provided, offering students information on all the controls (see Figs. 4 and 5). The help menu included a detailed explanation of each control along with video tutorials demonstrating how to use them. Finally, upon completing the simulation, AssessVR generated a data output file that students could access.

### 3.3. Utilitarian priming setting

In the Utilitarian priming scene, students were engaged with a non-

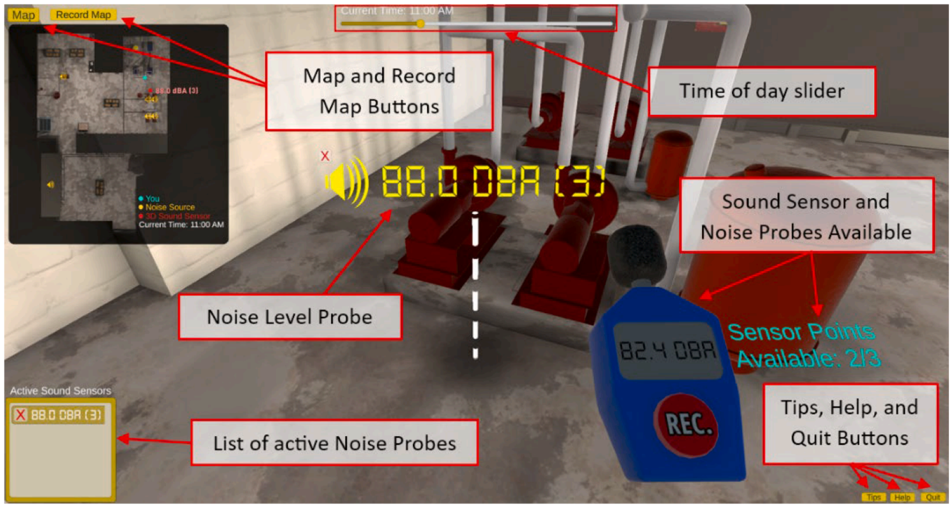


**Fig. 2.** Utilitarian priming setting and affordances.


**Fig. 3.** Tips menu in Utilitarian priming setting.

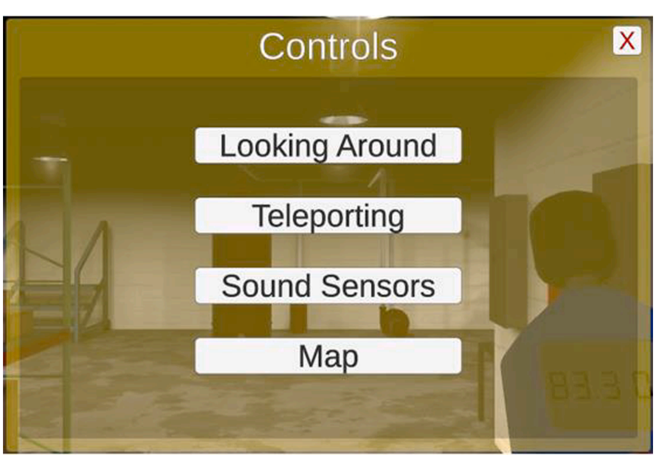


**Fig. 4.** The help menu.


**Fig. 5.** Sound sensors tutorial in controls menu.

gamified simulation of the machine room where noise originated from different sources as described earlier. They were provided access to a site map and carried a sound level meter as they navigated the virtual environment. A slider was available for controlling the time of day, and three noise level probes could be placed and removed as needed. The virtual environment featured a total of six noise sources. Fig. 2 displays a screenshot from the Utilitarian priming scene.

### 3.4. Focus group

In order to expand on the work by Yrjo et al. (2022), a focus group was formed to gather feedback and suggestions on how to improve the gamification elements of AssessVR. The focus group consisted of four individuals who identified themselves as gamers or frequent video games players. Three members of the group completed an industrial hygiene course prior to the formation of the group; none of them were involved in the final study. The focus group was introduced to the AssessVR tutorial and subsequently familiarized themselves with the gamified aspect of the simulation by completing the first iteration of the Gamified priming setting by Yrjo et al. (2022). After engaging with the first iteration of the gamified version, the group engaged in a discussion that was guided by the following questions:

1. What are your thoughts on the reward mechanics?
2. Would you like to see other mechanics?
3. What was your favorite part?
4. What was your least favorite part?
5. Did you find anything frustrating?
6. Were there any difficult to use or hard actions?
7. Were there any actions that were very easy to complete?
8. What stood out the most to you, and why?
9. If you could choose one thing to change, good or bad, what would it be, and why?

The results highlighted areas for improving usability and yielded additional features aiming to enhance player engagement. The group identified the fast-paced tutorial as a challenge, making it difficult to review important information and, thus, key game mechanics were not registered by participants. They also emphasized the need for a panel to manage active sound level probes and the inclusion of a help menu that outlines all the controls in the simulation, suggesting that implementing these features clearly would prevent overlooking vital information. Additionally, the group proposed implementing a quest or task feature to reinforce the covered topics and enhance engagement. Usability improvements were made in both the Utilitarian and Gamified settings based on this feedback; the task system was specifically integrated into the Gamified setting. These relevant tasks were designed to promote meaningful exploration and interaction in the simulation and were programmed into the simulation to facilitate the Gamified setting.

### 3.5. Gamified priming setting

The Gamified priming setting was identical to the Utilitarian setting. However, in addition to all the features in the Utilitarian priming setting, the Gamified priming setting featured serious game elements. These elements include an in-game shop where students could access upgrades, an in-game currency that could be collected through hints and quest completion, control panels for interacting with machines, and a visible probe placement optimization score that reflected the quality of the location of noise level probes.

The in-game shop (see Fig. 7) offered four upgrade choices: Upgraded Sensor, Enhanced Map, Sound Goggles that when used highlighted the sources of noise in bright orange, and Earplugs. These upgrades aimed to help students place noise level probes effectively and encouraged the use of countermeasures to earn additional currency.

To acquire the in-game currency, students had to interact with user interface (UI) hints that displayed information relevant to noise hazards and noise risk assessment (see Fig. 8), or the quests that tasked students with small goals they could accomplish in the priming setting (see Fig. 9). The quests consisted of opening the shop, viewing a different time of day, and finding a machine that reached 100 dBA during the day and turning it off. The quests and hints were designed to motivate students to explore the environment and utilize all the tools at their disposal.

In addition to the shop, students could interact with control panels (see Fig. 10). They could use their currency to repair damaged machines or turn machines off to decrease the room's noise level and boost their score. A control panel was positioned near each of the six noise-sources. Fig. 6 provides a screenshot of the Gamified priming setting.

As described in the experimental design, students engaged in a final setting after they completed their experience in the primed scenes.

### 3.6. Final setting

The final setting was the same machine room environment as in the Utilitarian and Gamified settings. However, it featured seven noise sources in different locations than those in the priming settings. Students had the same affordances that were provided in the Utilitarian priming setting, meaning that only the non-gamified features were incorporated. The students were asked to explore the machine room and pursue the same goals as with the priming setting. The simulator generated a data file at the end of the simulation. The data included noise level reading from probes they placed. The data-generating algorithm created data for an eight-hour time frame, with noise levels fluctuating throughout these eight hours. The students were informed that they would be asked to write a post-simulation risk assessment report and were expected to address the data generated.

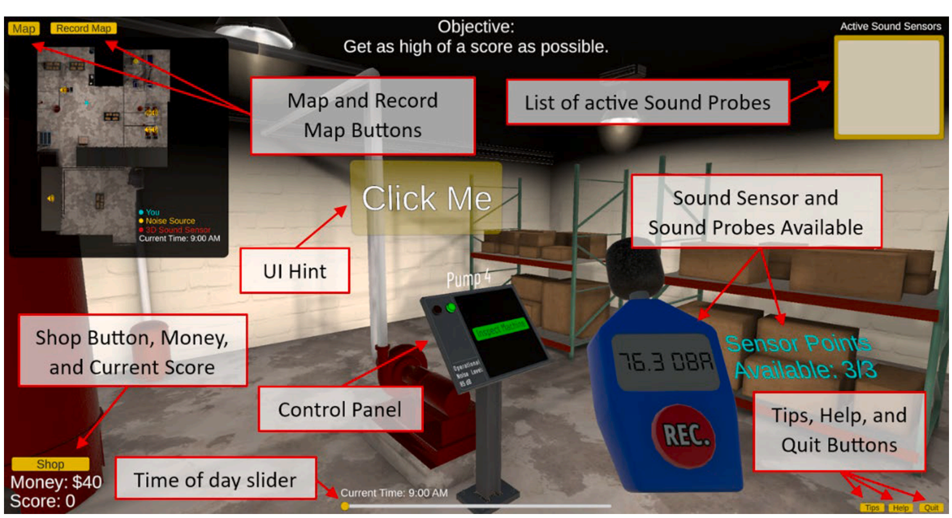


**Fig. 6.** The Gamified setting and affordances.

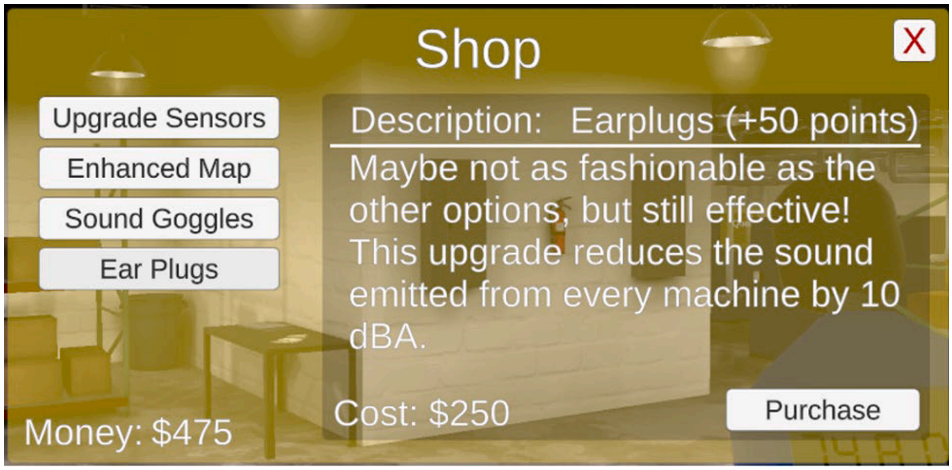


**Fig. 7.** The in-game shop.

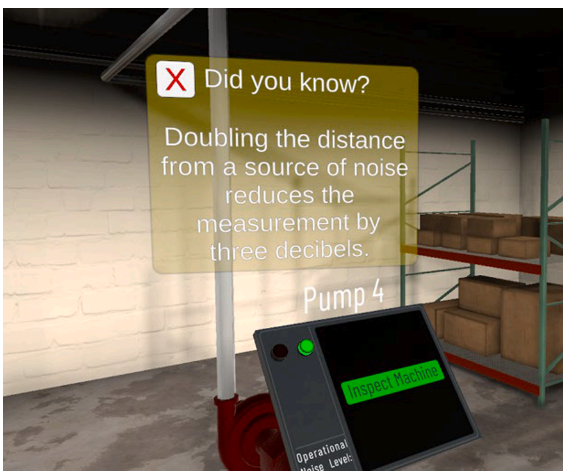


**Fig. 8.** An interactive UI hint.

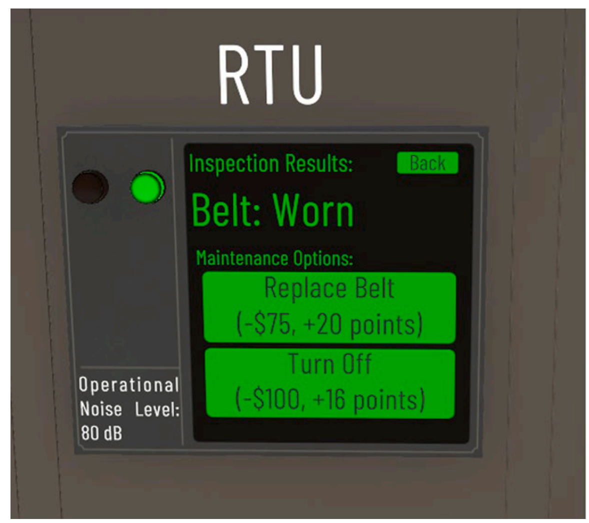


**Fig. 10.** A control panel.


**Fig. 9.** A quest in the simulation.

### *3.7. Post-simulation tasks*

After completing both the priming setting and the final setting, students responded to a 27-question survey. This survey included Presence assessment items (modified Slater-Usoh-Steed Presence Questionnaire (SUS-PQ) (Usoh et al., 2000), a modified version of the Gameful Experience Questionnaire (GEQ) (Högberg et al., 2019), and the NASA Task Load Index (NASA, 2020). Following the questionnaire, as mentioned above, they were requested to write a risk assessment evaluating the final setting and the noise hazards present in the room.

The SUS Presence instrument consisted of six items representing the following three Presence 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.

Students rated their level of agreement with the Presence items on a 7-point Likert scale. Table 1 presents the modified Presence SUS-PQ:

The NASA-TLX consisted of five questions to evaluate various dimensions of cognitive load. with a 7-point Likert scale (1 – Very Low, 7 – Very High). Table 2 presents the NASA-TLX questions:

The GEQ is a measure of the student's experience on the following aspects:

**Table 1**
The Slater-Usoh-Steed Presence Questionnaire.

| 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) 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 |

**Table 2**
The NASA Task Load Index.

| Code | Question | Task Load Dimension |
|---|---|---|
| Q7 | How mentally demanding was the task? | Mental Demand |
| Q8 | How hurried or rushed was the pace of the task? | Temporal Demand |
| Q9 | How successful were you in accomplishing what you were asked to do? | Performance |
| Q10 | How hard did you have to work to accomplish your level of performance? | Effort |
| Q11 | How insecure, discouraged, irritated, stressed, and annoyed were you? | Frustration |

1. **Accomplishment:** Experiencing the demand or drive for successful performance, goal achievement, and progress.
2. **Challenge:** Experiencing the demand for great effort in order to be successful, thus the ability of the student is tested.
3. **Competition:** Experiencing rivalry towards one or more actors (self, other person, service, or group) to gain a scarce outcome that is desirable for all actors.
4. **Guided:** Experiencing being guided on how (including what and when) to do, and on how to improve target behavior.
5. **Immersion:** All attention is taken over, and the person experiences being absorbed in what he or she is doing, while having a sense of being dissociated from the real world.
6. **Playfulness:** Tue experience of being in voluntary and pleasurable behaviors that are driven by imagination or exploration while being free from or being under spontaneously created rules.
7. **Social Experience:** The experiences emanating from the direct or indirect presence of people (both present in the real world and in the service), service-created social actors, and service as a social actor.

The modified GEQ used did not include aspects of social experience or competition as they did not apply to the simulation. Additionally, immersion was omitted as the SUS-PQ was used to assess levels of immersion and presence. GEQ items were rated on a 7-point Likert scale (1 – Strongly Disagree, 7 – Strongly Agree). Table 3 presents the modified GEQ:

### 3.8. Written analysis

The written risk assessment reports were evaluated based on the following main properties which are described in detail below: exposure assessment; control recommendations; and four risk assessment dimensions: hazard identification, reference to exposure standards, strategic reasoning, and strategic probe placement.

**Table 3**
The modified Gameful Experience Questionnaire.

| Code | Question | Gameful Aspect |
|---|---|---|
| Q12 | AssessVR makes me feel that I need to complete things | Accomplishment |
| Q13 | AssessVR motivates me to get better | Accomplishment |
| Q14 | AssessVR makes me feel like I have clear goals | Accomplishment |
| Q15 | AssessVR gives me the feeling that I need to reach goals | Accomplishment |
| Q16 | AssessVR challenges me | Challenge |
| Q17 | AssessVR calls for a lot of effort to be successful | Challenge |
| Q18 | AssessVR makes me push my limits | Challenge |
| Q19 | AssessVR makes me work at a level close to what I am capable of | Challenge |
| Q20 | AssessVR gives me a sense of being directed | Guided |
| Q21 | AssessVR gives me a sense of knowing what I need to do better | Guided |
| Q22 | AssessVR gives me useful feedback so I can adapt | Guided |
| Q23 | AssessVR gives me the feeling that I have an instructor | Guided |
| Q24 | AssessVR gives me an overall playful experience | Playfulness |
| Q25 | AssessVR gives me the feeling that I explore things | Playfulness |
| Q26 | AssessVR makes me feel like I discover new things | Playfulness |
| Q27 | AssessVR appeals to my curiosity | Playfulness |

Scores for each of the items, except for strategic placement and control recommendations, were either weak (one point), moderate (two points), or strong (three points) as described below. Outlined below are the dimensions pertaining to exposure assessment, control recommendations, and risk assessment.:

### 3.9. Score interpretation for exposure assessment

Exposure assessment is at the heart of the risk assessment evaluation as it is the process that determines the extent of the risk in the environment. Exposure assessment was evaluated on whether the student attempted to calculate the time-weighted average (TWA), not whether the student was correct. The list below describes the evaluation criteria of exposure assessment:

- Weak: The report did not include an attempt to assess occupational noise risk.
- Moderate: The report included a global assessment of exposure risk, but data-based exposure assessment was not provided.
- Strong: Detailed calculation of the TWAs were presented. Calculation accuracy was not assessed.

### 3.10. Control recommendations assessment

Proposing effective controls for noise exposure requires substantial experience, which the students lack. Therefore, the score for control recommendations in the reports was an additive scale with no maximum limit. The points assigned to each recommendation were based on the NIOSH Hierarchy of Controls as listed below:

- Personal Protective Equipment items: each received one point.
- Administrative controls: each received one point.
- Safety features: each received two points.
- Engineering controls: each received three points.
- Elimination controls: each received four points.

### 3.11. Risk assessment dimensions

#### 3.11.1. Hazard identification

- Weak: The report did not mention sources of noise.
- Moderate: Some, but not all sources of noise are reported.
- Strong: The report explicitly identified all noise sources.

#### 3.11.2. Reference to exposure standards

Examples of exposure standards are the U.S. Occupational Safety and Health Administration's (OSHA) 1910.95 standard for Occupational Noise Exposure, the U.S. National Institute of Occupational Safety and Health (NIOSH) established recommended exposure (REL); the U.S. American Conference of Governmental Industrial Hygienist (ACGIH) Threshold Limit Values (TLVs), etc. The scoring for the Reference to Exposure Standards in the reports was as follows:

- Weak: The report did not include a reference to exposure standards, or only list the standard by its title.
- Moderate: The report addressed either the OSHA Action level (AL) or the Permissible Exposure Limit (PEL) or the ACGIH TLV.
- Strong (three points): The report included reference to Action Level and exposure limit (PEL, TLV, REL)

### 3.12. Strategic reasoning

Hazard recognition is a fundamental component of risk assessment, serving as the first step in identifying potential threats to safety the environment. The ability to accurately recognize hazards is crucial as it sets the foundation for subsequent steps in the risk assessment process.

- Weak: The report did not demonstrate a strategic approach to the noise risk evaluation.
- Moderate: The report included some elements of strategic reasoning when justifying the assessment.
- Strong: A clear action plan for assessing the risk is presented.

### 3.13. Strategic placement

Upon closing the simulation, AssessVR generated a map of the environment, including the location of the probes the students placed. The map was overlaid on a noise level map calculated with equations (1) and (2). The strategic placement score was based on the probe's distance to closed noise level regimes presented in Fig. 11. The circles in the figure present local noise level maxima. The score was additive with a maximum of ten as follows:

- Probe placed in circle 1 (82 dBA maxima) was granted one point.
- Probe placed in circle 2 (84 dBA maxima) was granted one point.
- Probe placed in circle 3 (87 dBA maxima) received three points.


**Fig. 11.** Noise topology map with noise probe placement scoring circles.

- Probe placed in circle 4 (95 dBA) was granted five points.

### 3.14. Objectivity in evaluation: A dual-level review process

The initial analysis was undertaken by the first author. Following this preliminary assessment, a thorough review was performed jointly by both the first author and the corresponding author. The corresponding author has a substantial wealth of experience, with over twenty years in the field of risk assessments. This collaborative review process was carried out, item-by-item, in the report, until a consensus was reached. The rating procedure was found to be robust, and there were only minor adjustments required to the results of the preliminary evaluation.

## 4. Results

The questionnaire was administered to all students. Thirteen of the responses were from the Gamified group, and fourteen from the Utilitarian group. Although all students were asked to complete a written risk assessment report, only 11 reports were gathered from the Gamified group, and nine from the Utilitarian group.

### 4.1. Written risk assessment reports

Due to the low number of responses, a nonparametric Mann-Whitney *U* test was performed to evaluate exposure assessment, control recommendations, and each risk assessment dimension to document the differences between the two groups. Table 4 presents the results.

Exposure Assessment is at the core of risk assessment. The comparison indicated that the Gamified group score on Exposure Assessment was significantly higher than the score of the Utilitarian group, $z = -2.02$, $p = .0439$. The effect size was also large, $r = 0.452$. The comparison between the groups on Reference to Exposure Standards also revealed a significant main effect. The score of the Gamified group was statistically significantly higher than this score in the Utilitarian group, $z = -2.16$, $p = .0309$. Here too the effect size was large, $r = 0.483$.

No significant differences were found between the groups on hazard identification, strategic reasoning, strategic placement, and control recommendations.

### 4.2. Survey

A non-parametric Mann-Whitney *U* test was conducted to evaluate differences between the two groups for each item in the survey. Table 5 presents the means, standard deviations, and statistical evaluation for the items in the survey.

As presented in Table 5, there was significant main effect in question Q1: "I had a sense of "being there" in the machine room…" The results indicated that the Utilitarian group had significantly higher sense of the "being there" aspect of Presence than the Gamified group, $z = -2.54$, $p = .0110$, and the effect size was large, $r = 0.49$.

There was also significant main effect in question Q20: "AssessVR gives me a sense of being directed." The results indicated that the Gamified group had significantly higher sense of being directed than the Utilitarian group, $z = 2.59$, $p = .0097$, and the effect size was large, $r = 0.50$. No statistical differences were found for any other questionnaire questions.

## 5. Discussion

### 5.1. Risk assessment

This study investigated the effect of different priming settings on the quality of risk assessment in students studying occupational hearing loss. Various aspects of risk assessment quality and simulation experiences were analyzed. The findings indicated that the gamified approach significantly improved a key property of risk assessment, the "exposure

**Table 4**
Means, standard deviations, and Mann-Whitney *U* test results for each written assessment dimension.

| Assessment Property | Group | n | Mean | Standard Deviation | *Z* | *p* |
|---|---|---|---|---|---|---|
| Exposure Assessment | Gamified | 11 | 88.0 % | 16.7 % | −2.02 | **0.0439*** |
| | Utilitarian | 9 | 66.7 % | 23.7 % | | |
| Reference to Exposure Standards | Gamified | 11 | 81.7 % | 17.3 % | −2.16 | **0.0309*** |
| | Utilitarian | 9 | 59.3 % | 22.3 % | | |
| Hazard Identification | Gamified | 11 | 78.7 % | 6.7 % | −1.35 | 0.1765 |
| | Utilitarian | 9 | 63.0 % | 8.7 % | | |
| Strategic Reasoning | Gamified | 11 | 78.7 % | 27.0 % | −0.94 | 0.3485 |
| | Utilitarian | 9 | 66.7 % | 29.0 % | | |
| Strategic Placement | Gamified | 11 | 73.6 % | 21.5 % | 0.15 | 0.8774 |
| | Utilitarian | 9 | 74.4 % | 26.0 % | | |
| Control Recommendations | Gamified | 11 | 5.18 | 5.72 | −0.85 | 0.3972 |
| | Utilitarian | 9 | 3.56 | 4.19 | | |

**Table 5**
Survey analysis.

| Code | Group | n | Mean | Standard Deviation | *Z* | *p* |
|---|---|---|---|---|---|---|
| Q1 | GamifiedUtilitarian | 13 | 4.38 | 1.61 | −2.54 | **0.0110*** |
| | | 14 | 5.79 | 0.80 | | |
| Q2 | GamifiedUtilitarian | 13 | 3.54 | 1.66 | −0.64 | 0.5200 |
| | | 14 | 3.93 | 1.44 | | |
| Q3 | GamifiedUtilitarian | 13 | 4.54 | 1.51 | −0.42 | 0.6714 |
| | | 14 | 4.71 | 1.82 | | |
| Q4 | GamifiedUtilitarian | 13 | 4.00 | 2.00 | −1.58 | 0.1136 |
| | | 14 | 5.07 | 1.44 | | |
| Q5 | GamifiedUtilitarian | 13 | 3.15 | 1.41 | −0.47 | 0.6399 |
| | | 14 | 3.57 | 2.03 | | |
| Q6 | GamifiedUtilitarian | 13 | 3.23 | 1.92 | −1.16 | 0.2451 |
| | | 14 | 4.21 | 1.63 | | |
| Q7 | GamifiedUtilitarian | 13 | 2.92 | 1.26 | −0.05 | 0.9602 |
| | | 14 | 3.21 | 1.89 | | |
| Q8 | GamifiedUtilitarian | 13 | 2.31 | 1.11 | −0.43 | 0.6674 |
| | | 14 | 2.86 | 1.91 | | |
| Q9 | GamifiedUtilitarian | 13 | 5.31 | 0.85 | −1.75 | 0.0800 |
| | | 14 | 6.00 | 1.04 | | |
| Q10 | GamifiedUtilitarian | 13 | 3.38 | 1.33 | −0.20 | 0.8401 |
| | | 14 | 3.71 | 1.94 | | |
| Q11 | GamifiedUtilitarian | 13 | 2.31 | 1.60 | −0.56 | 0.5779 |
| | | 14 | 2.93 | 2.16 | | |
| Q12 | GamifiedUtilitarian | 13 | 4.08 | 2.02 | 0.10 | 0.9216 |
| | | 14 | 3.93 | 1.94 | | |
| Q13 | GamifiedUtilitarian | 13 | 4.00 | 2.04 | 0.20 | 0.8438 |
| | | 14 | 4.00 | 1.92 | | |
| Q14 | GamifiedUtilitarian | 13 | 4.38 | 1.66 | −0.12 | 0.9023 |
| | | 14 | 4.36 | 2.24 | | |
| Q15 | GamifiedUtilitarian | 13 | 4.46 | 1.98 | 0.52 | 0.6038 |
| | | 14 | 4.07 | 2.02 | | |
| Q16 | GamifiedUtilitarian | 13 | 3.62 | 1.33 | 1.15 | 0.2522 |
| | | 14 | 3.00 | 1.92 | | |
| Q17 | GamifiedUtilitarian | 13 | 2.46 | 1.33 | 0.15 | 0.8806 |
| | | 14 | 2.43 | 1.50 | | |
| Q18 | GamifiedUtilitarian | 13 | 2.54 | 1.27 | 1.26 | 0.2074 |
| | | 14 | 1.93 | 1.00 | | |
| Q19 | GamifiedUtilitarian | 13 | 3.92 | 1.93 | 0.99 | 0.3241 |
| | | 14 | 3.14 | 2.25 | | |
| Q20 | GamifiedUtilitarian | 13 | 4.62 | 1.71 | 2.59 | **0.0097*** |
| | | 14 | 2.71 | 1.68 | | |
| Q21 | GamifiedUtilitarian | 13 | 3.92 | 1.71 | 1.63 | 0.1039 |
| | | 14 | 2.86 | 1.61 | | |
| Q22 | GamifiedUtilitarian | 13 | 3.00 | 1.58 | −0.20 | 0.8432 |
| | | 14 | 3.21 | 1.72 | | |
| Q23 | GamifiedUtilitarian | 13 | 2.62 | 1.19 | −0.45 | 0.6543 |
| | | 14 | 3.00 | 1.71 | | |
| Q24 | GamifiedUtilitarian | 13 | 5.54 | 1.33 | 1.24 | 0.2136 |
| | | 14 | 4.36 | 2.21 | | |
| Q25 | GamifiedUtilitarian | 13 | 4.77 | 1.96 | 0.81 | 0.4157 |
| | | 14 | 4.14 | 2.14 | | |
| Q26 | GamifiedUtilitarian | 13 | 4.00 | 1.87 | 0.55 | 0.5856 |
| | | 14 | 3.71 | 1.86 | | |
| Q27 | GamifiedUtilitarian | 13 | 5.08 | 1.93 | 1.26 | 0.2087 |
| | | 14 | 4.07 | 2.16 | | |

assessment," and the "reference to exposure standards" dimension. Students in the Gamified setting reported a stronger sense of guided experience. On the other hand, students in the Utilitarian setting reported a significantly higher sense of "Being in the simulated scene" aspect of Presence. The effect sizes were large for all statistical significances. No significant differences were observed across the priming settings on hazard identification, strategic approach, and control recommendations.

Students in both groups reported a few of the noise sources, primarily focusing on sources exceeding 85 dBA. Interestingly, the Gamified group displayed a higher frequency of referencing occupational hearing loss exposure standards compared to the Utilitarian group. This can be attributed to in-game hints displaying occupational noise standards from various government entities. This observation indicates knowledge transfer from the Gamified priming setting to the students' risk assessments as reported by Roumell (2019). and is in line with the 'Principles that guide towards the intended behavioral outcomes' that are expected to lead to desired goals (Kraft et a., 2021). Furthermore, the Gamified group scored statistically significantly higher on exposure assessment, which can also be attributed to knowledge transfer from the in-game hints regarding time-weighted averages to the written risk assessments.

Both groups demonstrated strategic reasoning by formulating a plan of action to assess noise risk in the environment. On average, students in both groups achieved a score of around seven points for strategic placement, indicating that at least two out of the four noise level probes were placed optimally. Control recommendations did not vary between the groups; most students suggested personal protective equipment (PPE), such as earplugs, or administrative controls, like rotating shifts, along with engineering controls such as noise barriers or machine maintenance. Although the Gamified group received 78.1 % more points (57 points) for their control recommendations than the Utilitarian group (32 points), only students in the Gamified group recommended elimination controls, where ∼ 30 % of the students proposed turning off excessively loud machines. These suggestions reflect hazard elimination, the highest-level control in NIOSH's hierarchy of controls. This recommendation potentially stemmed from the presence of control panels in the Gamified setting, where students could switch sources of noise on and off. This effect is equivalent to the effect of lexical priming, where speakers are more likely to produce specific lexical structures when they are prompted by a similar utterance (Jackson, 2017; Kim & McDonough, 2008). The possibility of turning off sources of noise in the Gamified setting potentially influenced several students to include this suggestion in their final reports.

Viudes-Carbonell et al. (2021) discusses various design frameworks for improving education. They propose an iterative approach for serious game design. Symborski et al. (2017) report a serious game approach combining theory-based design with an iterative development strategy anchored in experimental tests and evaluation. Plecher et al. (2020) use a serious game to enhance language acquisition of Middle Egyptian language. They used a two-pre-studies iterative process to refine the game. Perry (2021) used a mixed method to develop an augmented reality language tool, where a design-based framework for game development was iterative, and the result of research from one version informed the design of the subsequent version.

According to the findings highlighted earlier, Hainey et al. (2023) suggest that priming effectively reduced the cognitive load for two specific dimensions: adherence to exposure standards and statistical reasoning. However, this benefit did not extend to other dimensions of risk assessment. This implies that the design of serious games aimed at facilitating the acquisition of risk assessment skills may require distinct game features tailored to each risk assessment element. Such a design approach could lead to a complex gamification process. It necessitates careful, and possibly iterative, scrutiny to ensure that enhancements in one dimension do not inadvertently impede development in others—a phenomenon that could be described as 'cross-contamination'.

### 5.2. Simulation experiences

The Utilitarian group reported a significantly higher sense of "being there" in the machine room compared to the Gamified group. The average score for the Utilitarian group was 5.79, with a standard deviation of 0.80, indicating a substantial level of presence. In contrast, the Gamified group reported only a moderate sense of presence. Inclusion of game elements in the Gamified setting may have compromised the authenticity of the machine room environment for these students (Weber et al., 2021). Both groups reported moderate-to-low levels of perception of the virtual environment as dominant over reality. Additionally, both groups expressed a moderate level of perception of the virtual environment as a place rather than simply a form of multimedia. It is worth noting that conducting a comprehensive, immersive virtual reality (IVR) study may yield different results in these dimensions.

All students, on average, reported experiencing moderate-to-low mental demand during the simulation. They also rated 'sense of urgency' low, suggesting that they had sufficient time to complete the tasks and did not feel rushed. Similarly, students indicated a sense of high level of performance in completing the simulation. Moreover, students from both groups indicated that they only needed to exert a moderate-to-low amount of effort to succeed, and also reported low levels of frustration. Potentially, the simulation provided a relatively straightforward and manageable experience leading to a low cognitive load.

Despite successfully completing the tasks of noise level probe placement and risk assessment, the modified GEQ results indicate that students from both groups expressed ambivalence towards the necessity of task completion and the clarity of the simulation's goal. This neutrality extended to their sense of motivation during the simulation, reflecting the contentious nature of serious games' motivational aspects in the literature (Wijers et al., 2008; Huizenga et al., 2007; Wouters et al., 2013).

Regarding the GEQ questions related to the gameful challenge aspect, students from both groups did not perceive the simulation as challenging. Consequently, they indicated minimal efforts were required to be successful. This lack of sense of a challenge may have resulted in lower engagement levels (Markey et al., 2014; Steinberger et al., 2017). Despite these low ratings, the Gamified group felt more guided, likely due to the inclusion of gamification elements such as upgrades, hints, points system, and control panels. However, both groups indicated the feedback in the simulation was insufficient for learning from mistakes, pointing to a need for improved feedback mechanisms in future iterations.

The simulation was seen to stimulate playfulness and curiosity across both groups, although it did not manage to fully encourage a sense of exploration or discovery. An expanded, more complex environment could potentially enrich these experiences; the current machine room scenario is notably simplistic and limited in size.

Gamified priming enhanced students' proficiency in occupational noise risk assessments. This result carries meaningful implications, hinting that integrating a gamified priming strategy could potentially enhance the effectiveness of safety professionals when conducting occupational noise risk assessments. By continuing to refine and expand AssessVR to encompass other risk dimensions, we may see improvements in broader risk management practices.

### 5.3. Training transfer

Scholarly evidence generally supports the effectiveness of knowledge and skill acquisition facilitated through virtual reality simulations. The integration of robust instructional methodologies, anchored in established pedagogical theories, is pivotal for enhancing the effectiveness of such training outcomes. However, our search for literature specifically concerning the transferability of learning for risk assessments from virtual environments to actual workplace settings failed to yield results. To bridge this gap, the research team is planning to conduct a study in collaboration with a safety laboratory course. This study will focus on students engaged in the evaluation of noise hazards within power plant operations, aiming to examine the transferability of risk assessment skills from the virtual training to real-world scenarios.

### 5.4. Contribution to body of knowledge

The current work extends the conventional discourse on serious games by elucidating the nuanced impacts of gamified learning in the specific context of safety education and training. While in some respects the paper reiterates the established benefits of serious games, its unique contribution lies in delving into the granular effects of gamification elements on learning specificities within occupational risk assessment—an underexplored domain in serious game studies.

This research uniquely contributes by empirically demonstrating that gamified environments can significantly enhance students' abilities to engage with and apply standards, such as those pertaining to occupational hearing loss, a benefit that may extend to other industrial hygiene domains. Notably, the study offers fresh insights into how specific game mechanics and post-game generative engagements can lead to improved higher-order learning outcomes, such as the strategic reasoning and consequently application of knowledge to real-world scenarios. These findings highlight the potential need for designing serious games with distinct features tailored to each element of risk assessment, ensuring that enhancements in one dimension do not impede development in others—a concept that could be termed 'cross-contamination', which may call for a substantial iterative development approach informed by direct learner feedback.

Moreover, this paper sheds light on the varying experiences of 'presence' in virtual environments, adding to the body of knowledge by exploring how presence is experienced differently in utilitarian versus gamified settings, especially within the realm of safety training.

Further, the work herein examines feedback mechanisms and their role in learning from mistakes, offering a more nuanced understanding of learner interaction with complex problem-solving in serious games.

In summary, the current work offers contextually grounded insights into tailoring gamification to enhance learning outcomes that require high-order learning and reasoning such as risk assessment skills acquisition.

Final note: the research team is planning to adjust AssessVR features to serve as a training tool to support risk assessment competence acquisition in industry professionals.

## 6. Conclusions

This research expands on the role of serious games in safety education and training, focusing on how gamification elements affect learning in occupational risk assessment, an area not extensively explored in serious game studies. The study demonstrates that, when combined with priming procedures, gamified environments improve students' abilities to conduct exposure assessments and apply exposure standards, indicating an enhancement in higher-order learning. The post-experiment survey indicated that subjects who underwent priming experienced a reduced sense of *Presence*, specifically the 'being there' (in the simulation) element, compared to the group that was not subjected to the priming procedure. Analysis of the *modified Gameful Experience* instrument showed that engaging in the gamification procedure led to a significantly higher sense of *'being directed'* compared to the group that was not subjected to the priming procedure, a desired outcome.

While the priming procedure enhanced the critical elements of risk assessment, such as *'Exposure Assessment'* and *'Reference to Exposure Standard*,' it did not benefit four other aspects of risk assessment, namely '*Hazard Identification*,' '*Strategic Reasoning*,' '*Strategic Placement of Sensors*,' and '*Control Recommendations*.' The current work offers contextually grounded insights into tailoring gamification to enhance learning outcomes that require high-order learning and reasoning, such as the acquisition of risk assessment skills. It also emphasizes a concern associated with targeting learning outcomes based on multiple learning and game theories that may lead to 'cross-contamination,' which may call for a substantial iterative development approach informed by direct learner feedback.

## 7. Limitations

There are two notable limitations to this study. The first is the small sample size. The pool of students with an industrial hygiene education background and the research team's outreach limit was a constraint. Additionally, AssessVR was developed for PCs with Windows operating system which prevented potential participants that use Mac PCs or Linux distributions from participating. A larger sample size could yield more generalizable results.

The second limitation is associated with engagement assessment. The multifaceted nature of engagement, as documented in existing literature, poses a significant challenge in identifying a precise, comprehensive measure that would encompass the various dimensions of engagement. This limitation is prevalent as the various definitions of engagement across literature indicate. Thus, selecting an appropriate measure that would adequately capture the complexity of engagement is a difficult task.

**Declaration of generative AI and AI-assisted technologies in the writing process**

During the preparation of this work the authors used OpenAI's ChatGPT in order to improve language and readability. After using ChatGPT, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the publication.

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## CRediT authorship contribution statement

**Tavion T. Yrjo:** Writing – original draft, Software, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Nir Keren:** Funding acquisition, Conceptualization, Methodology, Investigation, Analysis, Supervision, Writing – reviewing & editing. **Lorenzo Cena:** Writing – review & editing. **Stephen A. Simpson:** Writing – review & editing. **Richard T. Stone:** Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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