Using Non-immersive VR Simulations in Conjunction with Priming to Enhance Conceptualizing Radiation and Risk

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ABSTRACT

Radiation is present daily and used throughout many industries for beneficial purposes. Safety professionals and workers need a general understanding of radiation identification techniques and associated risks to manage the work environment with radiation protection practices. This is especially important in workplaces where the radiation source is ancillary to the primary activities of the industry. The elusive nature of radiation makes learners understanding in an educational setting a challenge. Furthermore, delivering a hands-on experience to support learning and training of radiation, its assessment, and protection measures is quite difficult, given its hazardous nature. Virtual reality, even using non-immersive environments, offers significant benefits through simulating sources of radiation. A non-immersive simulator titled AssessRadVR, facilitated the radiation experience and presented dynamically the effects of the trainees' interactions with shielding materials, detection equipment, and the working environment. Yet, interaction with simulation alone may not trigger effective encoding of these critical aspects in long-term memory.

This paper discusses using the AssessRadVR simulator in conjunction with a procedure for subliminally priming the long-term memory encoding to enhance radiation's activated representation. Students in an introductory industrial hygiene class were divided into two groups and primed with either alarming or non-alarming words following the Bargh, Chen, & Borrows procedure (1996). Results demonstrated that students primed with alarming words were more open to objectively evaluating the radiation sources due to their overall perception that the risk was manageable.

Why is this of interest to the community: The results provided that even with limited prior knowledge in radiation, after engaging with the simulator, most students were able to recognize and apply radiation principles, which indicates they could apply key principles in a real-world radiation workplace. Further, the impact of activating with alarming words led to a statistically significantly higher perception that working in the radiation environment was manageable.

ABOUT THE AUTHORS

Angela Leek, CHP is the Director for Radiological Solutions and Regulatory Affairs at Summit Exercises and Training, LLC, and is a graduate student in the Agriculture and Biosystems Engineering College at Iowa State University. Angela is a certified health physicist with more than 25 years of experience in radiation protection. Her research explores how mental models of radiation impact emergency responders' capacity to work in radiation environments and where virtual reality simulations can be leveraged to complete gaps in their mental models.

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Andrew Lawson is a Game Designer and VR Lab Manager at Iowa State University. He obtained a BFA in Graphic Design from the same institution in 2016. Andrew leverages virtual reality to develop serious games dedicated to education and training. As a VR Lab Manager, he collaborates closely with graduate students, contributing to the conception and creation of immersive virtual reality environments. These environments are designed for research studies in occupational safety, aimed at advancing knowledge and promoting safety practices in diverse occupational settings.

Aidan Webster is a Graduate Research Assistant at Iowa State University majoring in Industrial Agricultural Technology, focusing on Occupational Safety and co-majoring in Human-Computer Interaction. Aidan develops virtual reality simulations to study worker performance in various situations. His current area of research interest is utilizing AI-assisted feedback in training simulations.

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BACKGROUND

In the realm of workplace safety, the presence of hazards is an inevitable reality. While some hazards are readily identifiable and within our control, others are elusive: noise, radiation, and air quality concerns. These inconspicuous hazards, devoid of immediate or acute health effects, often evade detection and subsequently give rise to chronic health conditions that manifest after years of prolonged exposure.

Radiation safety professionals with a proper academic background or work experience can identify these hazards, evaluate their extent, and recommend controls for reducing risk levels. However, individual perceptions of radiation can impact decision-making and the ability to apply fundamental safety principles throughout a worker's assessment of an environment and the implementation of worker or public protections. Moreover, a significant obstacle in conveying the notion of radiation risk lies in distinguishing verified facts from speculations and segregating definitive truths from opinions grounded on partial information (Gonzalez, 2019). Even though a distinct separation might exist between the attribution of factual effects and the assumption of speculated risks, these concepts appear to be largely intertwined in the perception of individuals when assessing risks (Melo, 2019). The notion of risk carries various interpretations and implications, particularly in the context of radiation protection; therefore, given these uncertainties, it is important to find ways to assist inexperienced workers in conceptualizing and applying safety principles.

Equipping students to tackle the challenges inherent in their jobs can be conceptualized as a two-phase process. The initial phase involves a transformation in the learner's state of knowledge, such as the acquisition of new information. The subsequent phase sees the learner striving to master the knowledge obtained in the prior stage. This progression can be referred to as the "naïve-expert shift," as outlined by Wiser & Carey (Wiser & Carey, 1983). The naïve-expert shift encompasses a conceptual transformation, where successive changes occur in the student's approach to the mechanisms of the phenomena in question; their capacity to explain the workings of the system; and their understanding of the concept itself (Slezaka, 2022). It is important to recognize that as proficiency develops, the array of concepts may include notions that were non-existent prior to the shift.

Virtual Reality (VR) technology has been proven as a powerful tool for simulating hazardous environments and providing a safe and controlled setting for training workers on dealing with potential risks and emergencies. Researchers have found that VR has the capacity to mimic the physical and psychological pressures of hazardous work scenarios in a similar manner to real-life situations (Slezaka, 2019). For example, in industries where stressful or hazardous situations are common, VR training simulations improved workers' situational awareness and response times in real-life situations, particularly related to military medical training (Eubanks and Lopreiate, 2022). Moreover, studies have demonstrated that VR can help reduce the anxiety often associated with high-risk work environments, thereby increasing overall job performance through graduated stress exposure (Finseth et al., 2018). The combination of risk-free exposure, high-pressure simulation, and anxiety reduction contributes to the growing interest in VR as a training tool for hazardous working conditions.

The capacity for individuals to interpret phenomena, develop understandings, and learn can be influenced by their previous experiences or encoded beliefs. This can occur through priming, as outlined by findings from Srull and Wyer (1979), where they found that social stimulus can be biased by encoded trait concepts that, when present, influence an individual's subsequent interpretation of a person (Srull & Wyer, 1979). The specific type of encoding is indicated to hinge upon the accessibility of the relevant concepts at the point of information reception (Bruner, 1957). Relevant priming studies indicate that after an individual interprets the trait or behavior of another person and has encoded that specific trait in their beliefs, subsequent judgments about the person may rely more on the implications of this categorization rather than the actual behavioral traits demonstrated (Higgins, Rholes, & Jones, 1977). If this assertion holds true, a person's judgments about a hazardous environment may also be significantly influenced by prior trait encoding that makes one aspect of the hazard more accessible than others when the information about the hazard is initially obtained.

PROJECT GOALS

This project aimed to examine the influence of priming activities on an individual's ability to interpret radiation risks and apply protection principles within a radiation work environment. Based on literature in other sectors of occupation and industry demonstrating that priming may influence an individual's perception of risk concepts, this study also explored the potential impact of simulation activities on the learner's overall perception of the radiation risk and their ability to practically apply radiation protection concepts. This led to two research questions.

- What is the impact of priming on the following six dimensions of radiation protection principles presented in the simulation module: radiation type identification, distance, exposure pathways, shielding factors, protection strategies, and regulations?
- To what extent can the use of non-immersive virtual reality (VR) mitigate the influence of priming?

To examine these research questions, a subliminal priming procedure was implemented on students in an introductory industrial hygiene class; the procedure aimed at long-term memory encoding to enhance students' activated radiation representation. One group was primed with alarming words (the HH group) and the other with non-alarming (the LH group) following Bargh, Chen, & Borrow's procedure (1996). The hypothesis is that members of the HH group will approach the simulation with higher attention and focus, resulting in higher perception scores in all dimensions compared to the LH group.

THE SIMULATION

Ultimately, this project seeks to enhance educational strategies to improve confidence and understanding when assessing radiation risks in practical settings. The opportunity for engagement with the experiential learning simulation provided insight into how students may encode key radiation assessment and protection principles. An evaluation was conducted to assess how high and low levels of hazard awareness priming impact students' awareness and understanding of radiation risks while engaging in a radiation simulation assignment. The effectiveness of these priming activities was evaluated through post-simulation surveys, as well as assessment and coding of each student's ability to articulate key radiation principles in their final reports.

The simulator was designed for PC, where the simulation was delivered on the computer screen. The scene replicates an industrial machine room (see Figure 1), where the participants could navigate and interact with three radiation sources placed throughout the room. Within the simulation, the participants were provided with:

- simulated radiation equipment with a probe providing a window opening that allows for both alpha/beta/gamma (open window) and gamma-only (closed window) readings to be made.
- shielding materials consisting of paper, plastic, and lead,
- cones to establish a restriction zone, and
- a distance measurement device.

Figure 1. Machine room environment

Tutorial**:** Participants were provided access to tutorial objectives that offered instruction on how to interact with the various elements within the scene. These tutorial objectives were available throughout the session via a text prompt at the top of the screen, as seen in the top left corner of Figure 2. This text prompt changed based on the actions taken by the participants and guided them through the process of the simulation. The text prompt was always visible, so the participant could always understand their current task and how to use the system controls to manipulate the various aspects of the simulation.

Movement & Controls**:** Participants could navigate throughout the machine room in the scene by 'clicking' on any point on the floor, which resulted in subsequent teleportation to that chosen location. Moreover, the simulation facilitated an omnidirectional view within the scenario by allowing participants to hold the right mouse button and maneuver their mouse to look around. Participants selected each radiation source through a left click on the mouse, which would trigger a glow to signify the selection of the source. Upon selection, participants could deploy a radiation detector for measurement purposes. Fine adjustments to the position of this radiation detector probe could be made using the mouse scroll wheel for zooming in and out.

As described earlier, the experimental setup further enabled the selection of one among three distinct types of shielding: paper, plastic, and lead to aid in determining the type of radiation source present. Figure 2 presents the various operational features.

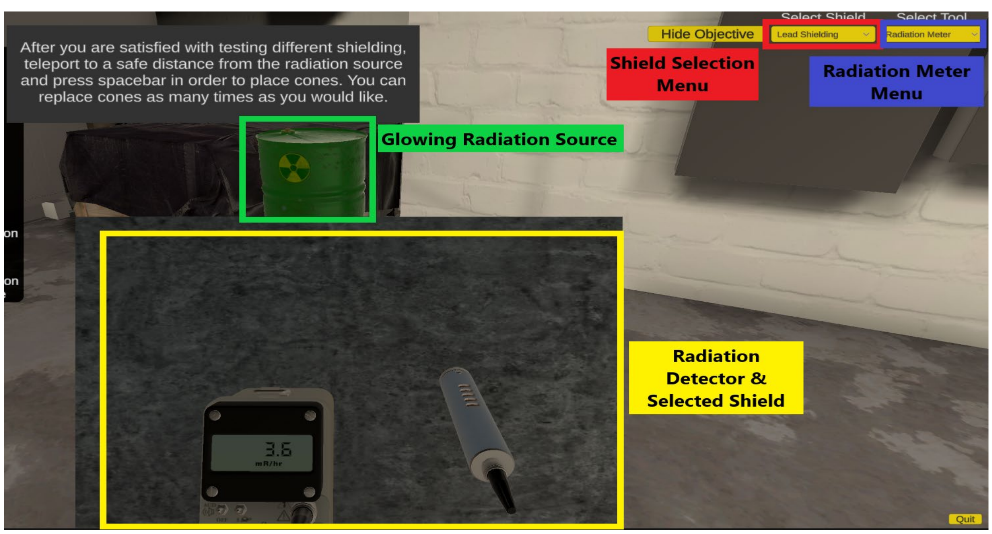

Figure 2. Simulation functionality

Additionally, the participant could delineate the safe distance from the selected radiation source by deploying cones around it. This action could be activated by pressing the spacebar, which would deploy the placement of a cone ring around the selected source. The spatial extent of this ring corresponded to the participant's current distance from the source, as seen in Figure 3.

Figure 3. Cone ring

Radiation Sources**:** The three radiation sources were of the following types:

- Source 1: Alpha Radiation (Figure 4. a)
- Source 2: Beta Radiation (Figure 4. b)
- Source 3: Gamma Radiation (Figure 4. c)

Each source was positioned in a unique location within the machine room and was placed relatively far away from each other to require the participant to move throughout the entire space to fully evaluate all hazards in the simulation.

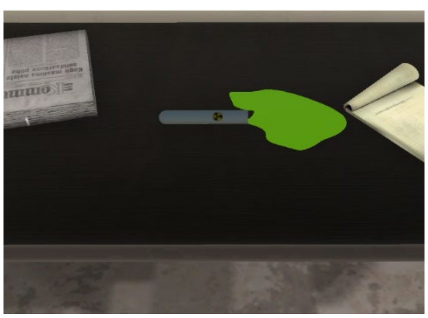

Figure 4a. Alpha Source **Figure 4b. Beta Source** **Figure 4. Gamma source**

Map and Objective Windows**:** A small map was always available for the participant to view. By clicking the buttons, the map would appear in a window in the top left corner of the screen and show the participant's location, as well as the locations of the radiation sources and cones that the participant had placed (Figure 5).

METHOD

All students registered for the course were engaged in a module incorporating three main tasks: (1) a word scramble activity, (2) a simulation, and (3) a post-simulation survey. Each student's interaction with the module was uniform; the only variance was the types of words provided in the word scramble activity, as follows: The class participants were randomly divided into two groups: High Hazard (HH) and Low Hazard (LH).

As mentioned earlier, in the word scramble activity, the HH group was presented with words that conveyed alarming characteristics, such as "danger" or "hot.” Conversely, the LH group was given neutral words, which were unlikely to elicit any particular response. To inject an element of stress into the activity, the HH group was urged to complete the word scramble as swiftly as possible, noting the time taken to complete the task. The LH group, in contrast, was neither subjected to any time constraints nor provided with any such prompt. Within the task, each participant was asked to construct a sentence using three out of four provided words they deemed most suitable. The activity did not necessitate a single correct answer but rather served as a method of interaction with the words in a priming context, as described in the procedure developed by Bargh, Chen, & Burrows (1996).

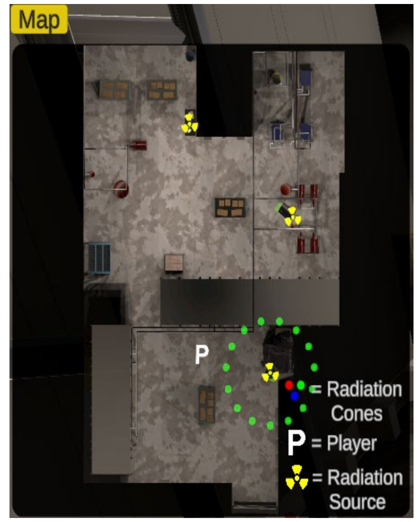

Figure 5. Map

After the word scramble, the participants immediately engaged in the simulation activity previously described. The participants were asked to interact with the simulation to identify the type of radiation emitted from each source using the radiation equipment readings, distance from the source, and interactions with various shielding materials. The participants were also asked to drop hazard cones to indicate the area around each source where entry should be restricted to life-saving activities only. Participants were asked to document their assessments and reasoning throughout the simulation for use in developing a final report. Upon exiting the simulation, participants were provided with a folder containing an Excel spreadsheet output of the radiation readings and distances for their interactions with each radiation source and a map of the area where the restricted zones were established. Each participant completed two post-simulation surveys, labeled “1” and “2” immediately after exiting the simulation activity. Each post-simulation survey prompted a series of questions using a Likert scale to assess the participant’s perceptions of the simulation and their actions. Survey 1 used a scale of 1 to 4, and Survey 2 used a scale of 1 to 7. Figure 6 presents the experimental process. Survey 1 and 2 questions are outlined in Figure 7 and Figure 8.

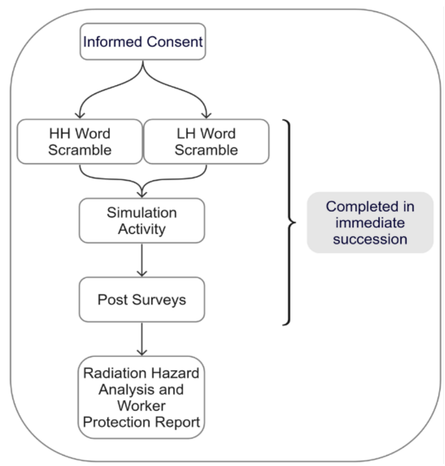

Figure 6. Experimental

Post Simulation - Survey 1 Questions
I felt content
I felt skillful
I felt rushed
I was fully occupied with the simulation environment
I felt confident
The radiation risk was manageable
I thought about other things
The radiation risk was a major hazard
It was a dangerous work area
I felt good
I felt bored
I felt urgency
Workers would be safe in this environment
I felt pressured
Workers would be seriously injured from radiation in this environment
I felt worried

Figure 7. Post-Simulation Survey 1 Questions

Post Simulation - Survey 2 Questions
How mentally demanding was the task?
How hurried or rushed was the pace of the task?
How successful were you at accomplishing what you were asked to do?
How hard did you have to work to accomplish your level of performance?
How insecure, discouraged, irritated, stressed and annoyed were you?

Figure 8. Post-Simulation Survey 2 Questions

Finally, each participant submitted a written report developed using the information they derived from interactions in the simulation. The participants were asked to provide details about the characteristics and identification of the radiation hazards and a proposed worker protection plan for the simulated environment. The information in the report was examined and coded to gauge the extent of their comprehension of key radiation protection concepts. These were identified as the dimensions of radiation type identification, shielding factors, distance, exposure pathways/risks, protection strategies, regulations, and their perception of the manageability of the radiation hazard risks overall. The adequacy of the content within the report was coded for each dimension by the researcher using qualitative scoring criteria on a scale shown in Table 2.

Table 1. Radiation protection report dimensions scoring rubric

Score Value	Adequacy of understanding of concept
5	Complete
3	Partial Explanation
1	Incomplete
0	Missing

RESULTS

The dataset was statistically analyzed with the JMP software package to identify potential relationships or correlations between the HH and LH groups, as well as within the survey questions and the coded participant report data. Throughout this analysis, when the statistical assumptions of normality, equal variance, and homogeneity were met, t-tests were performed, and when the data failed to meet these assumptions, non-parametric evaluations were conducted.

Post Simulation Survey Results

Only one question from the post-simulation surveys was statistically significantly different by group. Due to a lack of normality and equal variance, nonparametric Wilcoxon was used to document the differences. Table 2 provides the details for this:

Table 2. Post-simulation survey result details

Post-simulation survey question	LH			HH			S	Z	Prob≤ Z
	n	Mean Rank	Sum of Ranks	n	Mean Rank	Sum of Ranks			
The radiation risk was manageable	12	9.5833	115	12	15.4167	185	115	-2.0905	0.0366*

The Wilcoxon analysis revealed a significant main effect between the HH and LH groups relative to the participant's perception of the manageability of the radiation risk, z = -2.0905, $p < .0366$. While priming with alarming words significantly affected the perception of manageability, all other dimensions remained unaffected, including the perception of worry, potential injury, and pressure. These results are encouraging since none of the dimensions that could impact performance were affected, yet the perception of manageability, which is the desired outcome, was enhanced.

Participant Report Results

It should be noted that the number of participants for the LH group was reduced to 11 in this analysis due to an incomplete report submission by one of the participants for this portion of the data collection. The radiation protection report dimensions data analysis revealed two dimensions with a notable statistical difference between the HH and LH groups.

The first dimension, with a rather weak significant difference ($.1 > p \geq .05$), was related to the participants' ability to properly identify the radiation sources (Table 3).

Table 3. Participant report result details – Radiation Source Type Identification Dimension

Coded radiation protection report dimension	LH			HH			S	Z	Prob≤ Z
	n	Mean Rank	Sum of Ranks	n	Mean Rank	Sum of Ranks			
Radiation Source Type Identification	11	9.2273	101.5	12	14.5417	174.5	101.5	-1.9396	0.0524

The second notable finding (Table 4) in the coded radiation protection report dimensions also revealed a weak statistical significance related to the participants' reflection on the overall manageability of the radiation risks presented in the scene ($.1 > p > .5$). This result is further notable due to the relationship to the statistically significant finding related to manageability reported for the post-simulation survey data earlier.

Table 4. Participant report result details – Overall Risk – Manageability Dimension

Coded radiation protection report dimension	LH			HH			t-statistic	Prob≤ t
	n	Mean	SD	n	Mean	SD		
Overall Risk – Manageability	11	2.2727	1.4206	12	3.25	1.4848	-1.6128	0.0609

No other data from the coded radiation protection report dimensions significantly differed between the two groups.

Correlation of Radiation Protection Report Dimensions

Given the lack of difference demonstrated for most of the radiation protection report dimension data between the HH and LH groups, a correlation analysis was conducted for the entire participant cohort without grouping. The correlation between the overall risk manageability and each of the dimensions is provided in Table 5. The dimensions of 'distance' and 'protection factors' were highly correlated with the overall perception of manageability. The 'exposure pathway/risk' dimension was moderately correlated, and 'shielding factors' were mildly correlated with perceived manageability. Correlation results are presented in Table 5.

Table 5. Participant report result details - Correlation Matrix

DIMENSIONS	Overall Risk - Manageability		
	F-Ratio	R Squared Adj	p-value
Protection Factors	37.16	0.6217	<0.0001*
Distance	25.1076	0.5228	<0.0001*
Exposure Pathway/Risk	16.15	0.4079	0.0006*
Shielding Factors	6.8276	0.209	0.0162*
Radiation Type ID	2.8654	0.078	0.1053
Regulations	2.4579	0.062	0.1319

DISCUSSION

The results of this research demonstrate that subliminal priming with alarming words can influence the overall perception of radiation hazards and leads to a determination that working in the radiation area can be managed in a reasonable manner. Even in high exposure rate radiation work environments, the immediate health risk to employees is often minimal. Workers must comprehend that these environments with radiation hazards can be appropriately managed to enable accurate risk assessment, application of safety principles to reduce exposures and continue effective operations or response in the work area. The results indicated an improved perception of incident manageability on the radiation protection report dimensions and through the post-simulation survey answer of the same conceptual area. When the data was segmented by prompting, it was found that those primed with alarming words perceived the radiation hazard simulation as more manageable than those not primed. This extended to an enhanced ability to identify the radiation sources in the simulation, suggesting that the students were more open to objectively evaluating the radiation sources due to their overall perception that the risk was manageable.

While the effects of priming were observed in the concept areas of radiation source identification and overall hazard manageability, several other factors could also contribute to an increased perception of the overall manageability of risk in the simulation. Given that there was no significant difference between the hazard words and non-hazard words primed groups in the other radiation protection dimensions, a non-segmented analysis was conducted to investigate the relationship of the seven dimensions of the radiation protection report to identify any statistically significant correlations.

The analysis of the results demonstrated significant and highly correlated relationships between the overall perception of manageability and the core dimensions of radiation protection. These core dimensions include shielding factors, distance, exposure pathway/risk, and protection strategy. This suggests that the interactive elements within the simulation have the potential to mitigate the influence of priming and reinforce the essential concepts of radiation risk and perception. Notably, the lack of statistical significance in the correlation findings for regulation, which was not incorporated in the simulation, supports this hypothesis. These findings underscore the intricate interplay of various factors that shape the perception and comprehension of risk in radiation hazard simulations. They provide a compelling justification for further investigation and assessment in this specific domain, highlighting the importance of continued research and exploration.

The impact of priming on individuals' perception and response to hazardous situations is widely acknowledged in studies on public and worker behaviors. In this study, it was essential to investigate whether priming significantly impacted the fundamental perceptions related to radiation protection principles. The findings indicated that priming with alarming words prior to engaging with the radiation simulation improved the perception of two important dimensions of radiation protection concepts. Additionally, a correlation analysis suggested that non-immersive virtual reality could enhance overall foundational knowledge and risk perception, thereby mitigating the potential influence of predisposition caused by priming.

This study provides empirical support that although priming seemingly influenced students' application of two of the radiation protection dimensions within the simulation, the experiential engagements facilitated by non-immersive virtual reality (VR) appeared to mitigate any disparities between the primed and unprimed cohorts. These findings indicate that the non-immersive VR-based learning environment fosters a harmonious application of the radiation protection principles presented in the simulation module and supports the development of confidence in the manageability of the radiation hazards.

This finding is significant, which underscores the potential of VR as a powerful tool in the realm of radiation protection education, especially when it comes to minimizing the impact of pre-existing biases and enhancing students' understanding of complex concepts. Furthermore, this implies that the application of immersive technologies like VR can provide a consistent and effective learning experience, despite varying initial conditions introduced through activities such as priming. Future research could focus on leveraging these insights to further optimize educational strategies and enhance the understanding and application of radiation protection principles in practical scenarios.

CONCLUSIONS

The impact of priming on individuals' perception and response to hazardous situations is widely acknowledged in studies on public and worker behaviors. In this study, it was essential to investigate whether priming had a significant effect on the fundamental knowledge related to radiation protection principles. The findings indicated that priming with alarming words prior to engaging with the radiation simulation improved the perception of two important dimensions of radiation protection concepts. Additionally, a correlation analysis suggested that non-immersive virtual reality could enhance overall foundational knowledge and risk perception, thereby mitigating the potential influence of predisposition caused by priming.

LIMITATIONS

The class consisted of small numbers of students ranging from undergraduate to graduate level. Additional studies to increase numbers would be beneficial to further assess the correlation findings.

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