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# The Role of Haptic Feedback in Modulating Task Load in Immersive Learning Environments

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**Abstract.** The purpose of this study was to examine the effect of haptic feedback on learners' task load in an immersive virtual reality (VR)-based simulation environment. A total of 84 participants were randomly assigned to either a VR with haptic feedback group or a VR without haptic feedback group (n = 42 per group). The learning task was embedded in a simulation scenario designed to train procedural responses to a hazardous chemical spill incident. Task load was measured repeatedly at four time points during the learning process using the Simulation Task Load Index (SIM-TLX): before the simulation (pre-test), after the simple procedural simulation, after the complex procedural simulation, and after the debriefing session (post-test). A mixed-design repeated-measures ANOVA revealed a significant Time × Haptic interaction for frustration, $F(2.36, 187.58) = 5.64$, $p = .002$, $\eta^2p = .07$, indicating that haptic interaction dynamically modulated affective task load across learning stages. These findings contribute to understanding how embodied tactile interaction influences learners' cognitive and affective experience in immersive procedural training.

**Keywords:** Immersive Learning, Haptic Feedback, Task Load.

## 1 Introduction

Simulation-based learning is widely recognized as an effective instructional approach that provides learning environments similar to real-world situations and helps overcome the limitations of learning in actual contexts. Extended reality (XR) is an immersive media technology that integrates elements of the physical world with virtual elements, and it has strong potential for adoption in simulation-based learning environments because it can extend traditional forms of simulation and enable the design of diverse scenarios.

The multisensory virtual experiences afforded by XR environments can be implemented either by completely isolating learners from the real world or by supporting learning through the integration of real and virtual elements. In such environments, learners may experience *place illusion*—the feeling of being in a place depicted virtually even while knowing that they are not physically there and that the events are not actually occurring—and *plausibility*—the sense that the events perceived in the virtual environment are really happening. Through these experiences, learners tend to exhibit emotional and behavioral responses similar to those in real situations, which constitutes a key factor in enhancing perceived realism, presence and immersion [1, 2]. These characteristics offer a particularly meaningful advantage when designing simulation scenarios that must recreate hazardous or exceptional situations and contexts.

However, if the ultimate goal of XR-based simulation learning is to enable what is learned in virtual environments to be effectively transferred to real-world contexts [3-5], the educational effectiveness of approaches that completely isolate learners from the real environment remains open to debate. Implementing simulations in a way that connects real environments with virtual information and supports learning within authentic contexts may be more effective in enhancing transfer to actual performance. For example, Cooper and his colleagues [6] augmented real objects with multisensory cues and linked real-world contextual information to virtual simulations. Although this approach reduced the overall perceived realism or fidelity of the simulation environment, learners were able to transfer what they learned in the virtual setting more effectively to real-world tasks, and their learning performance also improved. At the same time, however, when virtual simulations are combined with real-world information, learners must attend to both the physical and virtual worlds simultaneously, which increases the likelihood of attentional distraction and may, in turn, undermine learners' perceived realism and immersion in the simulation environment [7, 8].

In this context, haptic feedback can be considered a key design factor that not only compensates for the weakened immersion and presence often observed in reality-connected XR environments but also facilitates transfer by strengthening embodied interaction through bodily sensations. That is, by enabling learners to *feel* the consequences of their actions beyond primarily visual and auditory interactions, haptics may amplify the transfer potential of XR simulations grounded in physical realism, while simultaneously reorganizing learners' attention and sense of presence.

Therefore, it is necessary to empirically examine how the manner in which the presence or absence of haptic feedback differentially influence learners' task load in immersive learning. In this study, both experimental conditions were implemented within immersive VR using a head-mounted display (HMD), differing only in the presence or absence of haptic feedback.

### 1.1 Research Question

Does the presence of haptic feedback in in immersive VR-based simulation lead to significant differences in learners' task load?

## 2 Theoretical Framework

### 2.1 Simulation-Based Learning and Knowledge Construction

Simulation-based learning (SBL) is grounded in the premise that learners can acquire knowledge and skills through practice in environments that approximate real-world task conditions, while avoiding the risks and constraints of actual settings. From a training perspective, the ultimate value of SBL lies not merely in performance within the simulated environment but in the extent to which learning transfers to real-world contexts [9, 10]. Contemporary research continues to emphasize transfer as the central criterion for evaluating the effectiveness of simulation-based instruction, particularly in high-stakes domains such as healthcare, safety, and technical training [11, 12]. Transfer is facilitated when simulations preserve critical features of real tasks, provide opportunities for active practice, and support meaningful feedback, thereby promoting the alignment between learning and application contexts [13]. Within XR-based simulations, design features such as interactive object manipulation and physically grounded feedback are therefore not ends in themselves but mechanisms intended to strengthen the functional correspondence between simulated practice and real-world performance. From this perspective, examining how different configurations of interactivity and sensory feedback influence learners' task load, self-efficacy, and embodiment is essential for understanding how XR simulations can be optimized to support transfer of learning. From a constructivist perspective, this process can also be conceptualized as knowledge construction grounded in embodied interaction.

### 2.2 Embodied Cognition

Prior research indicates that haptic feedback in VR can enhance procedural realism and motor accuracy; however, its impact on cognitive and affective workload remains mixed. Few studies have examined stage-based modulation of task load within immersive sessions, representing a gap addressed in this study. Embodied cognition posits that cognitive processes are fundamentally shaped by the body's interactions with the physical and social environment, rather than being confined to abstract mental representations alone [14, 15]. According to this view, perception, action, and cognition are tightly coupled, such that learning is grounded in sensorimotor experiences and bodily engagement with task-relevant objects and contexts. In technology-mediated learning environments, this perspective has motivated the design of interfaces that enable learners to act, manipulate, and receive feedback in ways that mirror real-world interactions, thereby fostering embodied forms of understanding. In XR-based simulations, interactive manipulation of virtual objects can enhance learners' sense of agency and action-perception coupling, while haptic feedback can further enrich embodiment by providing tactile and force-based sensations that anchor virtual actions in bodily experience. Prior research suggests that such embodied interactions can support deeper conceptual understanding, procedural fluency, and the formation of memory traces that are more readily transferable to real-world tasks [16, 17]. From an embodied cognition perspective, interactive and haptic design features are thus expected to shape learners' embodied experiences, which in turn may influence affective responses, cognitive load, and ultimately the transfer of learning from simulation to practice.

## 3 Methods

### 3.1 Participants

A total of 84 participants (aged 20–49 years) from the general population completed the experiment. Participants were randomly assigned to one of two experimental conditions ($n = 42$ per group).

### 3.2 Research Design

The independent variable was the presence of haptic feedback (VR with haptic feedback vs. VR without haptic feedback). The dependent variable was task load measured at four time points: pre-test, after Stage 1, after Stage 2, and post-test. The study employed a mixed-design with haptic feedback as the between-subjects factor and time (four levels) as the within-subjects repeated-measures factor. Table 1 presents the research design and the four experimental conditions corresponding to the independent variable.

**Table 1.** Research Design.

| Haptic Feedback | |
|---|---|
| Absent | Present |
| G1: Control group (interactive VR materials, without haptic feedback) | G2: Haptic-based XR simulation (with haptic feedback and interactive manipulation) |

### 3.3 Learning Task

Participants performed procedural response tasks in a simulated hazardous chemical leak scenario based on the *Laboratory Safety Management Emergency Response Manual* provided by the National Institute of Chemical Safety, Ministry of Environment [18]. Table 2 presents the simulation procedures.

**Table 2.** Learning Tasks and Measurements by SBL Procedure.

| SBL Procedure | Learning task | Measurement (Task load) |
|---|---|---|
| Stage 1. Pre-briefing and conceptual preparation. | Participants were introduced to the learning objectives, safety guidelines, and key concepts related to the scenario. | Pre-test |
| Stage 2. Simple procedural simulation. | Participants performed basic response procedures under guided conditions. | Post-Stage 2 |
| Stage 3. Complex procedural simulation. | Participants engaged in a more complex and integrated response task that required applying multiple procedures in sequence. | Post- Stage 3 |
| Stage 4. Debriefing. | Participants reflected on their performance and received feedback on their actions and decision making. | Post-test |

The haptic condition involved direct physical interaction with real objects embedded in the simulation environment, enabling participants to experience tactile sensations such as surface texture and resistance through actual contact.

### 3.4 Instruments

Task load was measured using a 10-item Simulation Task Load Index (SIM-TLX) questionnaire developed by Harris and colleagues [19]. The instrument assesses six dimensions: mental load, physical activity, temporal demand, task performance, effort, and frustration. Each item was rated on a 0–100 scale, with higher scores indicating greater perceived load. The internal consistency reliability was acceptable (Cronbach's $\alpha = .80$).

## 4 Results

Repeated-measures ANOVA conducted across the ten task load subdimensions revealed a statistically significant Time × Haptic interaction for frustration, $F(2.36, 187.58) = 5.64$, $p = .002$, $\eta^2 p = .07$. This finding indicates that the trajectory of perceived frustration differed across simulation stages depending on whether haptic interaction was present. Specifically, haptic interaction dynamically modulated affective task load as procedural complexity increased. No statistically significant interaction effects were observed for the remaining task load subdimensions.

## 5 Discussion & Conclusion

The present study examined how haptic interaction influences learners' task load across staged procedural learning in immersive VR. The significant Time × Haptic interaction for frustration suggests that tactile engagement with physical objects does not uniformly reduce workload but instead dynamically modulates affective task load as procedural complexity increases. From an embodied cognition perspective, direct tactile interaction reshapes learners' sensorimotor engagement with task demands, influencing emotional responses during complex performance phases rather than merely enhancing sensory realism.

These findings imply that haptic interaction should be strategically aligned with phases of heightened procedural integration rather than applied uniformly throughout training. Although the study focused on a specific hazardous chemical response scenario and relied primarily on perceived workload measures, it highlights the role of embodied tactile design in regulating affective experience within immersive learning environments and underscores the need for future research incorporating objective performance outcomes.

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