HistoLab VR: A User Elicitation Study Exploring the Potential of Virtual Reality Game-based Learning for Hazard Awareness

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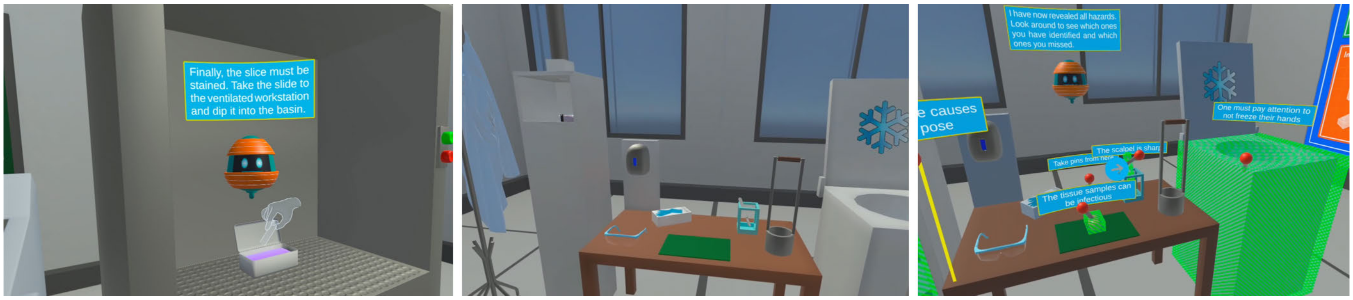

Figure 1: We designed, implemented, and evaluated *HistoLab VR*, a VR game to teach occupational medicine by raising awareness about various hazards within a histology lab. (Left) Introductory phase: A guiding robot familiarizes the player with the laboratory procedures. (Middle) Main phase: The learner follows the different steps of the fast-cut process in a virtual laboratory. (Right) Review phase: The learner identifies hazards related to this procedure and gets feedback from the robot.

Abstract

Occupational medicine is a vital field for workplace safety and health but often encounters challenges in engaging students and effectively communicating subtle yet critical workplace hazards. To tackle these issues, we developed HistoLab VR, a Virtual Reality (VR) game that immerses participants in a histology lab environment based on real-world practice. Our comprehensive user study with 17 students and experts assessed the game's impact on hazard awareness, interest in occupational medicine, and user experience through quantitative and qualitative measures. Our findings show that HistoLab VR not just immersed participants in a relatable histology lab worker experience but that it effectively raised awareness about subtle hazards and conveyed the inherent stress of the job. We discuss our results and highlight the potential of VR as a valuable educational tool for occupational medicine training.

CCS Concepts

• **Applied computing** → **Interactive learning environments**; Computer-managed instruction; • **Human-centered computing** → *Gestural input*; **Virtual reality**; *Scenario-based design*; *User centered design*; *Activity centered design.*

Keywords

histology laboratory, occupational medicine, hazard awareness, ergonomics, workplace, anxiety, education, serious games.

ACM Reference Format:
Robin Hänni, Tiffany Luong, Julia Chatain, Felix Mangold, Holger Dressel, and Christian Holz. 2024. HistoLab VR: A User Elicitation Study Exploring the Potential of Virtual Reality Game-based Learning for Hazard Awareness. In *30th ACM Symposium on Virtual Reality Software and Technology (VRST '24), October 09–11, 2024, Trier, Germany*. ACM, New York, NY, USA, 11 pages. https://doi.org/10.1145/3641825.3687723

1 Introduction

Occupational medicine is concerned with medical conditions that arise from hazards at the patient's workplace [21]. Hazards can be as obvious as the risk of injury from a table saw, but more often they are as subtle as the non-ergonomic posture induced by a table that is too low. Perhaps less well-known among the wider audience is that such seemingly mundane causes can result in severe symptoms, such as neck pain or headache.

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VRST '24, October 09–11, 2024, Trier, Germany
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ACM ISBN 979-8-4007-0535-9/24/10
https://doi.org/10.1145/3641825.3687723

Therefore, occupational physicians must have a good grasp of possible hazards across diverse workplaces and settings. This raises the considerable challenge of how to educate medical students of occupational medicine about these hazards and train them to behave correctly. While manuals and instructions for common hazards exist, they cannot adequately reflect the various hazard severities—or excite students about this important topic in the first place. Even during workplace visits, these hazards might not be apparent until students get firsthand experience, which is not always feasible during training as tasks can range from too dangerous to too rare because of required resources.

In this paper, we explore the potential of training students on hazard management through game-based learning. We particularly use Virtual Reality to translate the compelling immersive experiences to engaging firsthand experiences of workplace hazards for students. While Virtual Reality (VR) can provide safe environments, they are highly authentic and can thus foster learning through embodied experiences [6, 39]. Students can not only visit workplaces but to safely experience the work and related hazards inside.

In the case of histology labs, a variety of hazards is relevant. Workers have to process the incoming tissue samples under time pressure during fast-cut procedures. This creates a stressful environment that can induce anxiety. Ergonomics also play an important role, because the diverse set of tasks need to be executed at different workstations inside the lab. Transitioning between them can result in back pain, neck pain, and headache following bad posture due to insufficient adaptation of the workstation to a worker [17, 30]. Longer term, these conditions can induce chronic anxiety, severe infections, and fatigue, which, in addition to pain, raise the risk of human error inside these professional environments.

We present *HistoLab VR*, a VR-based educational game that we designed to raise awareness of hazards in students during firsthand experiences in a histology lab. We evaluate our environment in a user study that featured both *quantitative* as well as *qualitative* measures on usability and teaching occupational medicine. We recruited 17 students and experts from the field to interact inside the game and conducted expert interviews to identify areas for improved teaching. Our educational environment addresses the following research questions:

RQ1 How accurately does a VR-based replica of a physical histology lab reflect actual working conditions?
RQ2 What is the effect of a VR-based game environment on the subjective level of interest in occupational medicine?
RQ3 To what degree does the VR game align the player's state with the patient's state by increasing players' perceived anxiety?

We find that HistoLab VR's user experience successfully immersed participants in a histology lab worker experience. The results showed that our environment raised awareness about subtle yet critical hazards, and significantly increased the player's anxiety level, thus, conveying the stress of working in a histology lab. We also found that student and expert participants generally accepted VR as a teaching medium, recognizing its benefits for enabling the visit and firsthand experiences inside dangerous workplaces. Our game environment shows the feasibility of using VR in teaching occupational medicine, and our results outline the potential to raise the required awareness for hazards in trainees. Collectively, we make two main contributions in this paper:

- HistoLab VR, a game environment designed to raise awareness of hazards in a histology lab. The VR environment replicates a real-world lab to authentically communicate potential dangers.
- A quantitative and qualitative user study on HistoLab VR and, thus, VR as a medium to aid in the teaching of occupational medicine. Our findings show promising results for HistoLab VR and the considerable potential for VR in education in this domain.

2 Related work

HistoLab VR is related to the challenges of teaching and learning occupational medicine, the potential of VR for learning in general, and specific lab contexts.

2.1 Occupational Medicine Education

Occupational medicine focuses on "the recognition and prevention of occupational diseases, that is conditions caused or influenced by exposure to general conditions or specific hazards encountered in the work environment" [21]. Although this discipline is of primordial importance, it is often poorly and insufficiently taught [20], with very little impact on the undergraduate curriculum [16]. The learning process comprises of three phases: knowledge transfer, competence development, and professional inculcation [12]. The latter is of great importance yet most difficult to teach as it requires immersion in the work environment [12].

Different approaches have been explored such as text-based materials, case-based learning, or interaction with actual patients [16]. Text-based approaches perform worst, while interaction with patients performs best due to authenticity [2]. However, the tight schedule of physicians and students makes it difficult to attend extra courses in person and generally requires online solutions [51].

Such online solutions offer significant learning outcomes, similar to lecture settings [23]. Specifically, case-based online solutions are particularly promising as they offer a solution close to the actual duties and the related practical considerations [27].

In conclusion, occupational medicine is a difficult topic to teach as it requires authentic settings. Online solutions are interesting as they can be included in the tight schedules of medicine students. We now argue that VR offers a promising solution for occupational medicine education as it offers a case-based, authentic, online, and safe approach to the topic.

2.2 VR for Learning

VR can immerse users in a virtual world, through several sensory channels [32]. We focus our work on immersive VR through Head-Mounted Displays, immersing visual and auditory channels. Using VR to support teaching has been explored in various fields, such as mathematics [6], physics [40], ethics [41], and more [38].

VR is a powerful educational tool for several reasons: it makes abstract content concrete through dynamic, interactive visualizations and relatable first-person experiences [8]; offers a safe space for exploration and learning through productive failure without fear of harm or judgement [25, 26, 52]; provides otherwise impossible learning experiences due to cost, time, space, or danger [5]; enables exploration of others' perspectives and raises empathy, especially in medical contexts [13, 14, 44]; supports game-based learning [18, 47]; and offers embodied experiences by involving users' bodies [7, 49].

Previously, VR has been explored to teach hazard awareness in various domains, such as firefighter training for smoke hazards [54], mining worker instruction [11], risk prevention in the Architecture, Engineering, Construction, and Operations (AECO) sector [33], and occupational contexts [33]. However, these endeavors predominantly focus on the direct training of individuals who regularly encounter specific hazards during their work, and may overwhelm medical students seeking a comprehensive understanding of subtler hazards present in a workstation environment, such as ergonomic issues and potential tool-related risks.

Our work addresses this gap by developing a VR game that specifically targets the hazards explored within the domain of occupational medicine in a histology lab, and streamlines the learning experience, omitting extraneous details unrelated to hazard comprehension. A paramount design consideration for our game is its suitability for classroom instruction, ensuring that it harmonizes with the pedagogical needs of medical education.

Remarkably, to our knowledge, VR has been explored only minimally for teaching occupational medicine. Occupational medicine places a focus on empathy and the ability to appreciate the perspective of the worker. VR, in this context, offers a powerful tool to enable students and practitioners of occupational medicine to inhabit the work conditions of patients, fostering deeper understanding. Furthermore, our focus on hazard awareness within a histology lab conforms with VR technology's capacity to provide safe yet realistic learning environments. This approach minimizes student exposure to dangerous substances and equipment while mimicking authentic workplace conditions. Additionally, given that many hazards in this setting are physical and pose injury risks, our embodied VR approach meaningfully engages learners' bodies, rendering these dangers more concrete and relatable. Finally, we use a game-based approach to structure the learning experience and align it with the reality of occupational medicine.

Importantly, our goal is to explore the design and learning experience of occupational medicine in VR. We focus on hazard awareness as this is an aspect most difficult to teach, yet also most important. Our work is informed by practice and aims at offering a first exploration that can be directly impactful in the field. As such, we focus on design as well as learners' perspectives.

2.3 VR Laboratory Environments

Generally, VR is promising for improving occupational safety [22] and hazard awareness [46], but under-explored as the focus is on rehabilitation [24]. Moreover, to our knowledge, VR has not been used for occupational medicine education. To build a solid foundation of design principles for our own virtual histology application, we searched the literature specifically for lab environments in VR.

Garcia Fracaro et al. [19] propose a design framework for VR applications in chemical plant operator training. They show that the development procedure is an interdisciplinary task between the technical experts, teaching experts, and computer science specialists. Their design framework, which we follow, includes: (1) Content of the training: Include health, safety, and environment training, normal procedure training, and emergency training. (2) Modes of training: Include *exploration* to get familiar with the controls, *training* to learn the procedure with guidance, and *evaluation* to perform the procedure without guidance. (3) Include both game-based learning and assessment elements. (4) Carefully design performance reports and feedback.

De Micheli et al. [10] built a mixed reality application to enhance a laboratory course on microfluidics, using the principles of learning science: multimodal representations, control-of-variables, gamification, and instructional scaffolding. For our game, we followed the same principles: instructions and key learning points are presented in multiple modalities, the overall learning experience is gamified and the instructions are split into small chunks.

3 HistoLab VR Design

We designed HistoLab VR, a VR serious game that aims to familiarize players with occupational medicine-related hazards and conditions. Players take the role of a histology lab worker who must process tissue samples within a fast-paced environment.

To start our design process (aligned with RQ1), we first visited a real lab. This visit provided us with firsthand exposure to the operational procedures and workplace environment. The lab features two different tracks: *regular* and *fast-cut*.

The regular track offers detailed slow-paced tumor analysis. The fast-cut track provides a rapid (approximately 15 min) analysis to determine tumor presence. Lab workers prepare samples, while pathologists analyze them. Both stay in a confined space and work together while punctually maintaining communication with the surgeons. Due to the demanding nature of the fast-cut track, workers regularly switch between the two tracks.

Based on this information, we decided to focus on the *lab worker*'s tasks in the *fast-cut track* for our VR lab implementation as the work on this track is most challenging and highlights hazards that would be best conveyed through VR training.

3.1 Fast-cut Procedure and VR implementation

The fast-cut procedure, depicted in Figure 2, initiates when a surgeon sends a tissue sample through the mail, which the lab worker retrieves. In the fast-cut track, these scenarios can involve simultaneous requests and typically occur during surgical procedures, placing the lab worker under time pressure. The procedure comprises several steps, each on a dedicated work station. As our goal is to sensitize players to workplace hazards, rather than instruct them on histology lab processes, we simplified the steps as follow:

1. **Tissue preparation:** The lab worker cuts the tissue sample into smaller pieces to prepare it for freezing. In HistoLab VR, players place the tissue on a cutting bench, pick a knife, and cut multiple times along a line with an accepted error of 3 cm. The worker then puts the tissue sample into a container and fills it with a special gel that solidifies when frozen and binds the sample and the disk that is later inserted into the microtome. In our game, we simplified this step by automatically attaching the sample to the disk after the final cut.
2. **Freezing:** The sample is frozen in a liquid freezer. To maintain engagement, we expedited this by instantly freezing the sample upon interaction with the liquid.

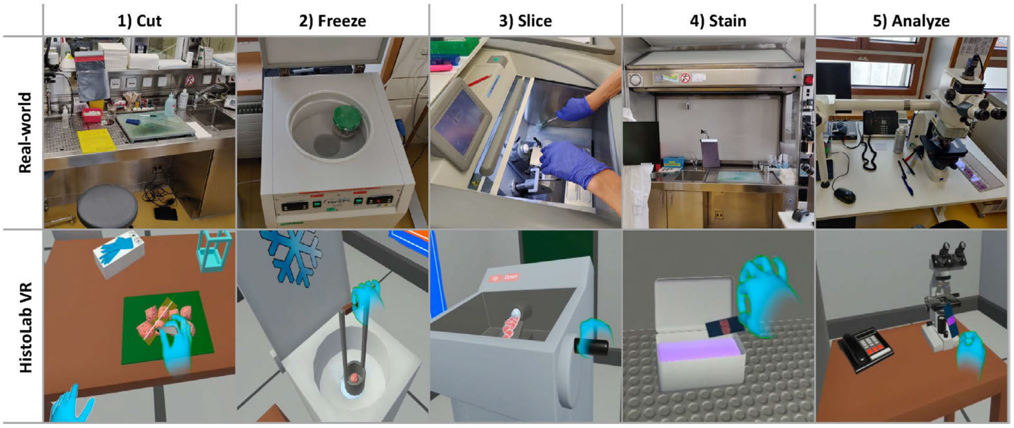


Figure 2: Histology lab fast-cut procedure to analyze tissues and provide a diagnosis related to tumors. The first row depicts the real-world workstations and the second row, HistoLab VR implementation. Each step is processed on a different workstation. First, the sample arrives via a small window (real-world) or via a tube mail capsule (HistoLab VR). Next, (1) the tissue is cut into a smaller piece. (2) The sample is lowered into a liquid freezer. (3) The sample is sliced using a microtome and placed on a glass slide. (4) The sample is stained under a ventilated workstation. (5) The finished slide is analyzed with the microscope.

(3) **Slicing:** The sample is sliced in the microtome. The microtome can be adjusted vertically through buttons to allow for an ergonomic position. As in the real world, players have to carefully place the frozen sample at the center of the microtome while avoiding the blade, then turn a crank at the side of the microtome to create slices of the sample. In reality, the slices created in the microtome are, then, picked up by the worker with a pair of pincers and laid flat on a glass slide for microscope inspection. Given the complexity of this interaction in VR, we automatically transform the sample into a prepared glass slide after the slicing operations.

(4) **Staining:** The slice is then stained with coloring agents in a ventilated area. As in the real world, the player dips the slide in a box filled with coloring agents. Similarly to freezing, this operation is performed faster than in the real world.

(5) **Analysis:** Pathologists analyze the finished slide using a microscope and relay findings to the surgeon. Players place the slide on a desk with a telephone and microscope, mimicking the setup but with a focus on the lab worker's role.

The game layout reproduces the physical arrangement of the lab. Players can seamlessly traverse the scene in an area of 3×1.7 m.

Regarding the workstation representations, we replicated each table, bench, and machine's shape and appearance, excluding minor details (e.g., button panels). Only relevant tools for VR interactions are displayed on each workstation.

3.2 HistoLab VR Gameplay

HistoLab VR comprises four phases:

3.2.1 VR interaction tutorial. VR learning activities should include a familiarization phase [7]. Therefore, we implemented a VR tutorial where the player first gets acquainted with the technology and virtual environment. They are instructed to walk to a target, try out interacting with objects (i.e., pick-and-place, throw, push), namely a box with a lid, a doll, and a button, and perform the thumbs-up gesture that is required to confirm instructions and proceed to the next step during gameplay. Instructions are presented by means of a floating robot that speaks to the player, including a text form as a panel above the robot.

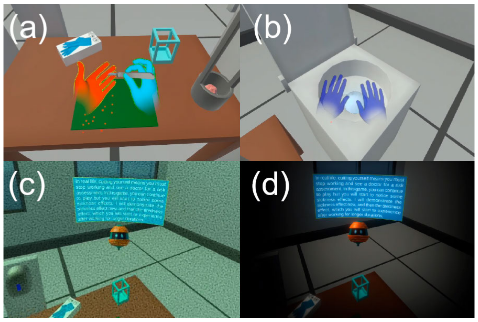


Figure 3: Hazard visuals effect: (a) bleeding hands after a cut, (b) frozen hands after contact with freezing liquid, (c) sickness effect after getting infected, (d) tiredness effect after working long enough.

3.2.2 Introduction. The introduction phase serves to explain the procedure of the fast-cut track (see Section 3.1) and serves as a tutorial of the game. The robot explains each operation and waits for the player to perform it correctly, giving contextual hints if the player takes too long or makes a mistake (Figure 1 (left part)). Animations of transparent 3D hands performing the required actions further aid in instructing the player. A poster with a summary of the processing steps remains visible during the entire game (see supplementary materials).

During this phase, the player is introduced to the story of a fictional lab worker who suffers from a headache and neck pain, which serves as a basis for the workplace investigation.

3.2.3 Main Phase. The main phase comprises several rounds of completing all steps of the fast-cut procedure (Section 3.1, Figure 2). Before starting, the player must wear a lab coat, safety glasses, and gloves. The game include the following hazards (Figure 3):

- **Time pressure:** The samples arrive with increasing frequency so that the player has less time to process them with each iteration. The delays between the arrival of the samples were piloted to the following values: 2 min, 90 sec, 30 sec, 10 sec, 1 sec, .5 sec, .1 sec. Each arrival is accompanied by a sound from the tube-mail.
- **Ergonomics:** The cutting desk is calibrated to a height that is uncomfortable for the player ($\max(h-1, .1)$ meters above ground, where h is the player's height).
- **Injury:** If the player touches a sharp object, their virtual hands turn red and start bleeding.
- **Freezing:** If the player comes in contact with the freezing liquid, their virtual hands slowly turn to a dark blue.
- **Dangerous chemicals:** A coughing sound plays if the player approaches the staining solution without the ventilation on.
- **Infection:** When touching the sample without gloves equipped, a green and grainy visual effect slowly fades in.
- **Social stress:** When taking over 2 min to process a sample, the surgeon repeatedly calls the pathologist to ask for the result. The conversation can be heard in the background.
- **Fatigue:** The longer the player is working, the smaller (vignetting effect) and the darker the field of view gets.

3.2.4 Review Phase. In the final phase of the game, the player is tested to check whether they have identified all the hazards of the workplace (Figure 4). The robot guides the player through the phase. The player must take pins and stick them to the objects that are dangerous or involved in a hazard. For certain hazards, we included representative objects (e.g. measuring bar for ergonomics, telephone for social stress). This aligns with the intended use of HistoLab VR: integrated into a broader educational context and accompanied by discussions where students reflect on the implications, for example how some hazards may result in fatigue.

Once the player confirms their selection by performing a thumbs-up gesture, the robot reveals all hazards and the player can read information about every hazard that is present. As a final step, the player is prompted to select the primary hazards responsible for the medical condition of the virtual patient introduced in the story. After confirmation, the robot reveals the solution and presents a detailed report of the player's performance. This gamification element motivates the learner to retry the main phase and achieve a better score by processing more samples and making fewer mistakes.

3.3 Design Decisions

The game is implemented using hand tracking to achieve as high immersion as possible and support an embodied experience of the hazards. We also kept the number of different interactions as minimal as possible, including only grab and poke interactions, to not overwhelm players. To confirm instructions we used the thumbs-up gesture since this is a known gesture.

We included a VR tutorial because we expected only few players had prior experience with VR and hand tracking.

Finally, although identifying hazards is important, once the cause of a medical condition is found, one also needs to find a solution to it. However, we did not include this part into the game as it relies on different cognitive mechanisms and skills and is not within the scope of this paper. In this regard, our activity should be considered as "preparation for future learning", as it activates students' prior knowledge, provides a safe space for productive failure [25, 26], creates curiosity and engagement with the problem at hand, and offers opportunities for conversations and consolidation in the subsequent lecture [3, 45]. Although this approach is quite beneficial for learning and medical training [48], it is still under-used to support occupational medicine education [34].

4 Evaluation Methods

To address our research questions (Section 1), we conducted a user study, divided into two parts: the game experience (quantitative part) and the expert interviews (qualitative part).

4.1 Tasks and Procedure

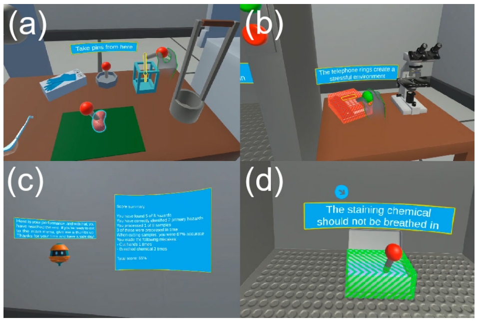
We started with an introduction to the study and a brief overview of the process. Participants then signed a consent form and filled out the pre-questionnaire (10 min). Afterward, we introduced them to VR and explained basic aspects of the technology (guardian system, hand tracking, object respawning). We then helped them equip the Shimmer sensor and set up the game. Once all measurements were confirmed to be running, they played all phases of the game (20 min, see Section 3 for details). After completing the play-through, they filled out the post-questionnaire (15 min). The experts additionally joined for a semi-structured interview (15 min).

The experiment lasted 45 min for students and 60 min for experts.

4.2 Collected Data

For the *quantitative* data analysis, we focused primarily on participants' hazard awareness, and examined game events, self-reported anxiety levels, and physiological responses. Additionally, we evaluated HistoLab VR's effectiveness in fostering an interest in the field of occupational medicine as well as its user experience.

In addition, we collected demographic information and other gameplay-related data such as physical exertion, presence, and



The telephone rings create a stressful environment

Here is your performance, and with that, you have reached the end. If you're ready to exit to the main menu, give me a thumbs up. Thanks for your time and have a safe day!

Score summary

You have found 5 of 8 hazards
You have correctly identified 2 primary hazards
You processed 1 of 8 samples
0 of these were processed in time
When cutting samples, you were 67% accurate
You made the following mistakes:
- Cut hands 1 times
- Breathed chemical 3 times

Total score: 55%

The staining chemical should not be breathed in

Figure 4: Review phase: (a) player selecting hazards with red pins, (b) player selecting primary hazards with green pins, (c) robot presenting score summary, (d) solution shown for a correctly identified hazard.

embodiment. These additional data points were gathered to gain insights into how they may influence our dependent variables.

For conciseness, as not all variables yielded significant effects or correlations with our variables of interest, we exclusively report results that involve the variables marked with a $*$ symbol below.

Pre-questionnaire. Demographics (age, gender, dominant hand, experience with videogames/VR, level of proficiency in German or English); State-Trait Anxiety Inventory (STAI) - Short Form Y1 [31]; General interest in occupational medicine (7-point Likert scale from "very low" to "very high").

During gameplay. Identified hazards during the review phase; Encountered hazard events during the main phase; Main phase completion time (until they either finish all samples or the global timer of 11 min runs out); Photoplethysmography (PPG) and electrodermal activity (EDA) signals using the Shimmer3 GSR+, wextracted features from these signals after filtering the motion artefacts and standardizing the signal features subject-wise.

Post-questionnaire. STAI - Short Form Y1 [31]; General interest in occupational medicine (as in pre-questionnaire); User Experience Questionnaire (UEQ) [28]; 26 items into six dimensions (Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation and Novelty); Borg's CR10 scale [1] to assess physical exertion; Adapted iGroup Presence Questionnaire (iPQ) [43] (items 1 on *sense of being there* and 7–10 on *involvement*); Adapted embodiment questionnaire [37] (items 4, 5 and 8–13, excluding appearance and multisensory items); Open feedback text box.

For the *qualitative* analysis, we conducted a semi-structured interview with questions about usability and areas of improvement with the experts to address our three research questions (questions detailed in in supplementary materials). We recorded the interview with an audio recorder and later transcribed the answers.

4.3 Apparatus

Based on availability, we conducted the experiment in two seminar rooms in our institution. Both rooms had similar lighting conditions, for optimal hand-tracking. We marked the playable area (about 3.5 × 1.7 m) with masking tape and placed an arrow, indicating the starting facing direction. Each participant wore an Meta Quest 2 (MQ2) headset with an MQ2 Elite strap with battery and a Shimmer3 GSR+ physiological sensor, recording PPG and EDA signals.

Interaction with the game relies purely on head- and hand-tracking. We compiled the game for standalone playing on the MQ2 and all recorded data was stored on its internal storage. We enabled screen recording on the headset before it was given to the participant. We tested the setting to ensure an average framerate of 70 FPS. Finally, all questionnaires were filled on a tablet.

4.4 Participants

Via e-mail in our research institutions, we recruited 17 participants: 4 students in medicine, 6 students from various other studies (mostly computer science), and 7 experts (Table 2). The mean age of the experts was 46.4 years ($SD = 5.8$). The age range of the students was 22-26, with one exception in the range of 40-44 years old ($M = 25.7$, $SD = 5.6$). All students are male. Only one out of all participants stated that they use VR "Several times a month", whereas all others chose the option "Less". The study was approved by ETH Ethics Commission (EK 2022-N-204).

Table 1: Characteristics of the analyzed study sample. Age is summarized as M (SD) and ratios are provided for gender.

Variable	Data ($N = 17$)
Age [22–54] (in years)	34.24 (12.03)
Gender	
% Male	64.7% ($n = 11$)
% Female	35.3% ($n = 6$)
Prior VR experience [1–4] (median)	1
Gaming frequency [1–4] (median)	1

Table 2: Expert participant's profiles. Experts participated both in the quantitative and qualitative parts of the study, whereas students only participated in the quantitative part.

Id	Age	Gender	Expertise
P1	45–49	F	Occupational physician
P2	45–49	F	Occupational physician
P3	45–49	M	Occupational physician in training, advanced
P4	35–39	F	Occupational physician in training, beginner
P5	50–54	F	Occupational hygienist
P6	50–54	F	Histology lab supervisor
P7	40–44	F	Didactic expert

5 Results

5.1 Quantitative Analysis

To evaluate the effectiveness of the game in raising hazard awareness, we tallied the frequency with which each hazard was correctly identified during the game's review phase. Generally, we used a Shapiro-Wilk test combined with visual interpretation of the QQ-plot to check the normality assumption. If the Shapiro-Wilk test was not significant ($p \geq 0.05$) and the QQ-plot appeared normal, we assumed that the normality assumption was respected and proceeded with parametric tests. Otherwise, we would have used non-parametric tests, but this situation did not occur.

For anxiety and interest in occupational medicine, we conducted a factorial analysis utilizing *time* (before vs. after the game) as a within-subject factor, and the participants' *profile* (expert, student) as a between-subject factor. A mixed ANOVA was employed for anxiety (Shapiro-Wilk $p = 0.131$ and Box's M $p = 0.861$), while an aligned rank transform (ART) ANOVA was utilized for assessing interest due to the ordinal nature of the data. All factorial analyses were carried out using R.

5.1.1 Hazard identification. Table 3 shows a detailed breakdown of how often each hazard was identified. All participants consistently recognized the microtome blade as a hazard. Interestingly, the staining solution, microtome height, freezer, and tissue sample garnered higher identification rates among the experts than among the students. Conversely, the table height, scalpel, and telephone were more frequently identified by students compared to experts.

Table 3: Percentage of times each hazard was identified in the review phase by students, experts, and in total. Hazards in bold indicate correct identification as the primary cause of the patient's condition.

Hazard	**Experts ($N = 7$)**	**Students ($N = 10$)**	**Total**
Microtome blade	100%	100%	100%
Table height	86%	100%	94%
Staining solution	86%	80%	82%
Scalpel	71%	80%	76%
Microtome height	71%	70%	71%
Freezer	71%	50%	59%
Table height	57%	60%	59%
Telephone	29%	30%	29%
Tissue sample	57%	10%	29%
Microtome height	71%	0%	29%
Telephone	29%	20%	24%

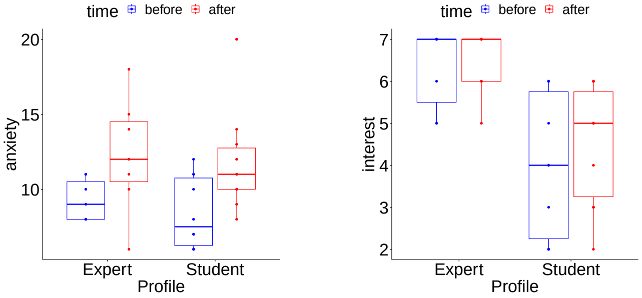


Figure 5: Anxiety and interest levels before and after playing the game, grouped by profile.

5.1.2 *Anxiety.* The mixed ANOVA revealed a significant effect of time on the STAI score ($F = 10.98$, $p = 0.005$, $\eta^2 = 0.249$): HistoLab VR significantly increased participants' anxiety (Figure 5). We did not find a significant difference between profiles ($p = 0.529$) nor a significant interaction effect between time and profile ($p = 0.839$).

5.1.3 *Interest in Occupational Medicine.* The ART ANOVA revealed that experts had overall more interest in occupational medicine than students ($F = 14.15$, $p = 0.002$, $\eta^2 = 0.49$). We did not find any significant effect of time ($F = 3.47$, $p = 0.082$) nor significant interaction effect between time and profile ($p = 0.146$). The data is plotted in Figure 5.

5.1.4 *User Experience Benchmark.* Based on the spreadsheet provided by the UEQ's authors, HistoLab VR performed at least "good" (10% of results better, 75% of results worse) in all dimensions of the user experience questionnaire with an "excellent" score (in the range of the 10% best results) in Perspicuity, compared to other software (468 studies, 21175 people). The results are depicted in Figure 6 and the score values are provided in supplementary materials.

5.2 Qualitative Analysis

We use an inductive thematic approach [4, 9] to analyze the interviews with the experts (Table 2). We include a theme if at least two experts made a statement on the same theme or if the statement concerned a topic from the specific expertise of the participant. The interviews were mostly conducted in German and the extracts found in the paper have hence been translated.

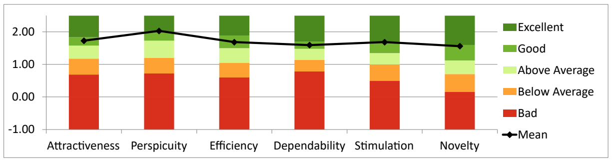


Figure 6: UEQ results in comparison to the benchmark.

Our overall thematic analysis of the interviews resulted in four main themes: game design, VR technology, learning, and hazards.

5.2.1 *Game Design.* One key goal of the interview was to identify problematic parts of the game. The analysis shows that many participants struggled with the review phase of the game. Similarly, many found the cutting interaction to be hard or confusing:

"I found it very very difficult to cut accurately with the scalpel and I do not know why" (P7), "Identifying the [hazards] was a little bit complicated for me to understand. I did not get how to do it with the red and green pins right away." (P2)

Another large topic is how the game represents the workplace overall. Certain incorrect representations of the real workplace were mentioned, on the other hand, it was stated that it does not feel important to correct them. Many participants also said that they think the reality is well represented. Regarding the entire field of occupational medicine, it was stated that the game, with its single workplace, only shows a fraction thereof:

"Of course there are finesses and things that are not [correct], but that is not important" (P6), "The procedures are well made in my opinion. I have never worked at such a workplace, but I have the feeling that it was implemented very close to reality, it is really astonishing" (P3), "We focus on one workplace and that is really a small portion of occupational medicine" (P1)

5.2.2 *VR Technology.* The most frequently addressed topic concerning VR is the interaction. Many participants said that they were struggling with grabbing objects. Several people also mentioned that haptic feedback and smells are key factors that are missing:

"I struggled with virtually grabbing [...] as I did not feel the material" (P7), "The tactile sensation has a feedback function and you somehow need this because based on that you take decisions or act accordingly" (P5), "It would be nice if one could smell [...] that is something that is also important for occupational medicine when one visits a workplace you should also use your nose to smell things" (P1)

Moreover, many participants recognized that VR can adapt to different workplaces and provide access to new workplaces:

"How would you let a student experience this otherwise, it is realistically not possible [...] with the workload that we have and concerning security and in the fast cut track everybody is always tense anyways. One cannot [let the student perform the task] and if they only peek for three minutes, then they do not feel it" (P6), "One could implement it for many different workplaces, such a game" (P3)

5.2.3 Learning. Since the game has the goal of teaching occupational medicine, the topic of learning came up in multiple interviews. One particularly interesting suggestion was to add a preview phase: *"It is conceivable that one looks around the lab in advance and thinks about what the hazards could possibly be because that is most likely the way you would do it in reality. [...] This has the additional effect that it might show the students that the things you see when visiting a workplace might not be the things that are actually dangerous." (P7)*

Last but not least, participants talked about the benefits and shortcomings of the game regarding learning, where almost all found it to be beneficial: *"It opens the possibility to experience the theory and for that, I believe, it adds value [...] it closes the gap between pure theory and experiencing it in reality" (P7), "In my opinion, it would be easier for students to go to a lab [...] and have a script alongside [...] In my opinion, the required effort to play the game is not worth [...] the learning effect." (P5), "I find it a good method because it is close to reality and the student does not need to visit the lab, because that is not realistically possible and even if the student comes for a visit, they do not experience the hazards themselves. So from that point of view, I find it a very elegant solution" (P6)*

5.2.4 Hazards. The primary goal of the game is to raise hazard awareness. When discussing hazard representations, every hazard was mentioned by at least one participant. Most hazards received both positive and negative feedback regarding their clarity.

Stress and ergonomics are the two most mentioned ones and all but one expert stated them positively. The risk of injury from the sharp devices, the infection hazard, and the unpleasant fumes from the staining solution were also discussed. The cutting danger and the risk of infection each were mentioned positively by all but one expert. The staining solution (chemical hazard) was mentioned both positively and negatively. A few participants made positive comments about the freezing hazard:

"It shows the stress, [...] the constant phone calls in the background, I found those annoying" (P6), "The ergonomics were very well addressed, I could feel my back being low on the table" (P2), "The cutting [hazard] was extremely well addressed." (P2), "It shows the hazard of infection because it is unfixed tissue" (P6) "I believe the chemical hazard has come across" (P5), "I did not realize that [the staining solution] could also be a danger" (P3), "I find it good that [the liquid freezer] is steaming" (P5)

6 Discussion

We presented HistoLab VR, a game to raise awareness for hazards in a histology lab, and evaluated the game in a study with quantitative and qualitative measures. The study was conducted with 7 experts and 10 students. In this section, we discuss our results in alignment with our research questions: game design and technological aspects, increasing interest in occupational medicine, and creating authentic experiences for students to relate with patients.

6.1 VR game design for occupational medicine

With our VR game, we offer a close to authentic experience of an actual workplace. In particular, no matter which hazards were experienced, almost all participants felt like they were in the position of the lab worker, in alignment with the desired learning effect.

The quantitative results showed that students demonstrated a superior hazard recognition rate when hazards were visually or audibly presented in a straightforward manner (telephone, scalpel, table height). In contrast, experts exhibited better hazard identification with hazards associated with machinery (freezer, microtome height) or bio-hazardous materials (tissue sample), which have more severe consequences. This suggests that while the game offers valuable experiential learning, it serves best as a complementary tool to traditional classes informing students about the risks associated with specific professional tools and contexts. This aligns with the chosen "preparation for future learning" pedagogical pattern [25, 26, 45].

The feedback on the experienced intensity did not always line up with the hazard identified in the review phase. For example, while stress was widely felt, only 5 of 17 players marked the telephone as a hazard. This result shows, again, that it remains important to discuss the hazards of a working place after playing such a game.

Previous studies utilizing VR to enhance hazard awareness often exposed participants to striking stimuli, such as wildfires [54], large-scale hazards related to AECO [33], or natural disasters [35, 50]. Noteworthy in our context is that, despite our simulation being conducted on a much smaller scale within a typical workplace laboratory setting to tackle subtle hazards associated with symptoms such as dizziness due to repetitive motion and ergonomy issues, the fact that 75% of all players successfully identified at least three hazards demonstrates that the hazard representations were clear and recognizable, regardless of the intensity of their experience.

We also identified possible future improvements. In particular, the review phase is not explained clearly enough. We will improve the game in future iterations to clarify the interactions in that phase. Concretely, we will add a short tutorial on the correct usage of the pins, right before the identification of the hazards.

Although hands were tracked adequately, limitations were evident during the study. Participants found grabbing interactions challenging without haptic feedback, and hand tracking introduced minor issues like reduced precision for performing fine motor interactions like cutting in a straight line. However, despite these limitations, participants reported high user experience scores using the standardized UEQ and the enthusiasm that was shown by almost all experts, showing that the technology is recognized for what it can do well despite its limitations. The statements about VR enabling the visit of dangerous workplaces also line up with previous literature [36]. As VR technology will continue to evolve to address these limitations, approaches such as ours offer promising perspectives for the teaching of occupational medicine.

6.2 Increasing interest in occupational medicine

The second goal of our game was to increase interest in occupational medicine by offering a case-based experience of actual tasks that practitioners must solve. Generally, occupational medicine, an indispensable discipline for workplace safety and health, presents challenges in effectively teaching students due to the limitations of conventional methods, which may lack engagement, or the busy schedules of physicians, leaving little room for authentic case studies. VR is promising as it provides immersive, engaging, and hands-on learning experiences that can greatly enhance understanding and awareness of workplace hazards. By presenting a real use case within a typical workplace laboratory setting through storytelling, we provide students with a relatable and engaging scenario.

The quantitative results show a visible trend, though not statistically significant, that the game has a positive effect on the interest in occupational medicine. As expected, experts showed significantly more interest that students, many of whom were not medical students. To figure out whether the game can significantly raise interest in the occupational medicine field, further analysis on a larger cohort of students would need to be done.

The qualitative results reflect these findings. Participants' comments on the game's purpose as a 'good' tool refer to its suitability in teaching occupational medicine, but they do not conclusively allow judging raised interest. However, interest and learning were found to be positively related in past work [42].

All in all, the results look promising regarding a possible confirmation of the hypothesis about the effect of the game on interest, however, further investigation is necessary to actually confirm it.

6.3 Creating authentic and relatable experiences

Finally, as previous work demonstrated the importance of connecting with actual patients in order to learn occupational medicine [2, 16], we were interested in using VR as a medium to create a relatable experience of a workplace, from the perspective of the patient. Specifically, we evaluated whether such activity can align the student or practitioner state with the patient state.

Both in the quantitative as well as the qualitative results we find evidence that HistoLab VR successfully conveyed the stress of the fast-cut track job and raised participants' anxiety level significantly. Whether this rise in anxiety comes from the particular gameplay or the mere fact of being in an unknown environment (VR) is not evident from our data. However, the responses from the interviews indicate that the former is at least part of the reason.

The qualitative results give further insight into which stressors seem to work best: the recurring telephone calls as well as the ergonomic discomfort were mentioned by almost all participants as disturbing. In contrast, the infection risk, chemical hazard, and freezing hazard received little mention, especially from the students.

The physiological signals, on the other hand, did not exhibit a clear stress response to the in-game events, which might be due to motion artifacts and physical activity overshadowing any potential anxiety-related effects on physiological response.

6.4 Limitations and Future Work

While our study provides valuable insights into the use of VR in educational medicine, particularly in raising awareness about subtle hazards associated with repetitive stimuli, ergonomics, and stress, it also points to the need for future research, including comprehensive large-scale studies. These studies should involve a diverse cohort of students with improved gender balance, compare traditional methods of teaching occupational medicine with VR interventions, and include a pre- and post-test for robust evaluation of learning [15].

To the best of our knowledge, there is currently no consensus on the methods for effectively evaluating occupational medicine knowledge, especially considering its strong association with case-based learning. VR applications such as HistoLab VR hold the promise to address this challenge by offering a platform to portray authentic occupational medicine use cases and assess them objectively. Additionally, they have the potential to evaluate students' practical field skills, which are often overlooked in traditional educational curricula due to logistical complexities and limited access to real-world settings. This could represent a significant advancement in the assessment of occupational medicine competence.

Our prototype design and implementation can serve as a basis for future developments of specific workplaces that focus on other types of hazards. To be reliably usable at home without further instructions from a teacher, we will iterate on the implementation of HistoLab VR to include a preview phase as well as improve the instructions in the review phase.

Given the expert's feedback on the haptic and olfactory feedback, further research could investigate the impact of multisensory feedback on raising hazard awareness within similar contexts featuring subtle hazards. Additionally, future studies could explore aspects such as knowledge retention among students who undergo such VR-based training or isolating and analyzing the individual effects of storytelling vs. the VR medium itself on hazard recognition.

7 Conclusion

We have presented HistoLab VR, an educational game for teaching occupational medicine, specifically to raise awareness about hazards in a histology lab. We evaluated our environment in a study with 10 students and 7 experts in occupational medicine, histopathology, and didactics. Through quantitative and qualitative analyses, we established that HistoLab VR effectively immerses participants in the role of a lab worker, raises awareness about subtle hazard representation in a typical lab setting, and conveys the inherent stress of the job.

Analyzing the interviews with occupational medicine and didactics experts showed that the virtual environment can suitably aid teaching occupational medicine. In addition to good user experience scores, we have also shown participants' acceptance of VR for teaching histology environments.

Our research advocates for the use of VR as a teaching tool for occupational medicine, and we hope it will inspire the creation of additional games that increase awareness of hazards in various other work environments. Future work could extend the review phase of game environments to further uncover the interest of non-experts in occupational medicine. Furthermore, as people's way of working and workspaces are evolving [29, 53], we believe that exploring fast and expedient ways of simulating professional workspaces is important for occupational medicine. Our work contributes to this endeavor by offering a first exploration of VR usage to teach and learn occupational medicine in a virtual field.

Acknowledgments

We thank Martina Storz and her team for letting us visit the histology lab of USZ and providing us with detailed insights into the process of the real workplace. We also thank all the people who contributed to the project by participating in the study, the brainstorming session and by proof-reading this document. This work received funding from the Lehrkredit of University of Zurich.

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