A Pedagogical Model for Immersive Virtual Reality Safety Training: Mixed-Methods Research

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PRESENTED AT:

AERA i-Presentation Gallery
2023 ANNUAL MEETING

I-PRESENTATION AUTHOR’S EDITING SITE
INTRODUCTION

Technological advances and the decreasing cost of virtual reality (VR) equipment have made immersive virtual reality (IVR) more available to educators and researchers (Elbamby et al., 2018). As a learning environment, IVR supports learner motivation, engagement and enjoyment, and its emotion-inducing features seem to suit occupational safety training particularly well (Nykänen et al., 2020; Casey et al., 2021; Makransky & Lilleholt, 2018).

However, the role of cognitive and affective factors in IVR learning effectiveness is still unclear (e.g. Makransky et al., 2019). Furthermore, IVR research has remained disconnected from learning theories (Radhakrishnan et al., 2021; Radianti et al., 2020).

We addressed this research gap by developing a theoretically grounded and empirically tested pedagogical model for IVR safety training. This poster reports preliminary results from both quantitative and qualitative data analysis upon completion of the empirical data collection. The results will contribute to IVR learning research and advance the design of the pedagogical model.
METHOD

Design-Based Research

Our project employs design-based research (DBR), which is directly applicable to the study of learning technology and pedagogical innovations (Anderson & Shattuck, 2012; Wang & Hannafin, 2005; Zheng, 2015), and involves developing theory and models in cooperation with participant organisations.

Quantitative and qualitative data were collected in authentic learning situations and analysed using mixed methods. Qualitative data allows a deeper examination of the quantitative results.

The pedagogical model will be further developed on the basis of these analyses, and iteration will continue in consequent design cycles (Anderson & Shattuck, 2012; Design-Based Research Collective, 2003).

Research Questions

1. How does IVR interactivity accommodate for the IVR affordances perceived by the learner?
2. How does IVR interactivity affect the learner’s cognitive load?
THEORETICAL FRAMEWORK

Pedagogical model for IVR safety training

Our pedagogical model is based on simulation pedagogy (Dieckmann, 2009; Kesktalio et al., 2010) and IVR learning research (Baceviciute et al., 2020; Makransky & Petersen, 2021). Thematic interviews were also conducted with the participant organisations’ safety trainers to contextualise the model in the domain of occupational safety (Lehikko et al., 2022).

The model depicts learning goals and objectives (Andersen et al., 2001; Kraiger et al., 1993; Krathwohl et al., 1973), considers the cognitive and affective factors in IVR learning such as cognitive load (Skulmowski & Xu, 2022; Sweller, 2020), and proposes IVR affordances such as sense of presence and sense of agency (Johnson-Glenberg, 2019; Kilteni et al., 2012; Lee, 2004; Odermatt et al., 2021).

The proposed model involves facilitated group discussions before and after individual IVR training scenarios. Our use of group discussions stems from the sociocultural view of learning (Säljö, 2009; Vygotsky, 1978). The pedagogical model comprises four training phases: introduction, IVR briefing, IVR scenarios, and debriefing.

**Introduction**
- The trainer introduces the course outline, topic and key concepts. This helps regulate the learners’ cognitive load (Dieckmann & Ringsted, 2013; Meyer et al., 2019; Sweller, 2020).
- The learning goals and the learners’ previous experience with IVR are discussed. To ensure relevance to the learners, the trainer includes practical examples from the learners’ professional context (Billett, 2021; Casey et al., 2021; Lehikko et al., 2022).
- The trainer supports the learners’ agency and encourages active participation (Bandura, 1997).
- The learners connect the training to their own experiences while making sense of the content and setting their own learning goals (Keskitalo et al., 2010; Casey et al., 2021; Dieckmann, 2009; Vygotsky, 1978).

**IVR Briefing**
- The trainer introduces the equipment, showing the learners how to wear the headset correctly and comfortably and how to hold the controllers (Bandura, 1997; Meyer et al., 2019; Vygotsky, 1978).
- The learners are directed to their individual training areas, where they are equipped to start the pre-programmed IVR tutorial. The tutorial instructs each learner to move around and to interact with the IVR environment (Meyer et al., 2019; Sweller, 2020).

**IVR Scenario**
- IVR environment guides the learner to interact with its content and delivers feedback on learner actions (Bandura, 1997; Johnson-Glenberg, 2019).
- The learner can move around freely and act independently within the scenario’s narrative, which incorporates the pre-determined learning goals. This accommodates learner self-efficacy and motivation (Bandura, 1997; Dieckmann, 2009; Makransky & Petersen, 2021; Ryan & Deci, 2000) and supports embodied learning, which may improve lesson retention (Johnson-Glenberg, 2019; Kilteni et al., 2012).

**Debriefing**
- The trainer facilitates learner agency and participation by modulating the emotional atmosphere, providing positive feedback and creating opportunities for positive affect (Bandura, 1997; Dieckmann, 2009).
- The learners are guided to evaluate, reflect on and analyze the IVR training experience. The group discusses the learning goals (Sutherland et al., 2009; Säljö, 2004; Vygotsky, 1978).
- The trainer helps the learners link the training experience and content to their work and to their organisations’ training objectives (Billett, 2021; Dieckmann, 2009).
PROCEDURE

Experiment Design

The degree of interactivity (Steuer, 1992) was hypothesised to affect perceived IVR affordances measures and cognitive load (Makransky & Petersen, 2021).

A valve works safety training scenario that was thematically unrelated to the procedures of either participant organisation was chosen from an existing selection of IVR occupational safety training content. Two experimental treatments were set: two versions of an IVR training scenario were prepared, one version with high interactivity and another one with limited interactivity. The same learning content was maintained across these versions.

Participants were randomized to either high interactivity (Treatment A) or limited interactivity (Treatment B). In the training sessions, participants performed the IVR training scenario version for their treatment. The post-scenario T2A questionnaire included sense of agency measures (Polito et al. 2013), sense of presence measures (Schubert et al., 2001; Witmer & Singer, 1994) and cognitive load measures (Klepsch et al., 2017).

IVR Training Environment

The IVR training environment that was used in this study was developed for occupational safety training at Finnish Institute of Occupational Health. The environment was accessed with a wireless head-mounted display and two hand controllers. Both versions of the IVR scenario required a four by four meters floor area that was free of obstructions for each learner, so that they could walk around freely when proceeding in the scenario script.

See examples clipped from a tutorial and a customs inspection themed safety training scenario in the video below.


Video credit: FIOH/Virtuario

Training Sessions

The training sessions were carried out by the participant organisations’ training personnel. The trainers had been instructed in carrying out the training in accordance to the pedagogical model and provided with a structured discussion guide (Eppich & Cheng, 2015; Feng et al., 2021, Lehikko et al., 2023) to facilitate the group sessions.

One session took approximately two hours to complete and it consisted of a trainer-facilitated introduction, two IVR scenarios, both followed by a questionnaire, and a trainer-facilitated debriefing discussion.

• 22 occupational safety training sessions in groups of 2-4 learners in 2022.
• Two participant organizations: a government services organisation and an energy-sector company.

Data Collection

Data were collected through questionnaires, video recordings, observations, and stimulated recall interviews (STRI).
Baseline questionnaire data were collected on 76 participants one to two weeks prior to the training.

68 chose to participate in the training and all 68 filled out the T2A questionnaire relevant to this study.

Questionnaire respondents: Treatment A n=33, Treatment B n=35.

Qualitative data was collected from 23 participants in 8 training groups.

STRIs were held with 9 participants from government services organization 14 participants from energy sector company.

Interviewees: Treatment A n=12, Treatment B n=11.

Interview transcripts were submitted to theory-driven content analysis in NVivo (Bengtsson, 2016)
LIMITATIONS AND NEXT STEPS

Limitations

The small number of participants and the differences between organizational samples are a clear limitation for the quantitative part of this mixed methods study. Qualitative data and analysis methods will be used for triangulation. However, the qualitative content analysis for this study was performed by only one researcher.

Next Steps

- Between-treatments analysis will be continued and conclusions will be made based on the results.
- Organisational datasets will be examined separately.
- Learning outcome measures will be reported.
- We will also study the individual learners’ background variables, such as previous IVR experience.

Key Concepts

**Immersive Virtual Reality (IVR)**
- Computer-generated, artificial 3D environment that is accessed and manipulated with a head-mounted display and hand controllers (Concannon et al., 2019)

**Interactivity**
- Control and immediacy of action that one experiences in IVR (Steuer, 1992)

**IVR Affordances**
- Sense of Agency: Feeling of initiating and performing actions within the IVR environment (Braun et al., 2018)
- Sense of Presence: Feeling of being ‘there’, surrounded by and immersed in the IVR environment (Schubert et al., 2001; Parong et al., 2020)

**Cognitive Load**
- Extraneous CL: Considered detrimental to learning, generated by IVR features and presentation of the learning content (Sweller, 2020)
- germane CL: Considered beneficial as it indicates cognitive engagement (Klepsch et al., 2017)

### Research Question

1) How does IVR interactivity accommodate for the IVR affordances perceived by the learner?

2) How does IVR interactivity affect the learner’s cognitive load?

### Object of Study

**IVR AFFORDANCES**

- Sense of Agency
- Sense of Presence

**COGNITIVE LOAD**

- Extraneous CL
- germane CL

### Key Concept

- Pritchard et al. (2018)
- Schubert et al. (2001)
- Witmer and Singer (1994)
- Klepsch et al. (2015)

### Quantitative Measure

- Spatial
- Control

### Coding Reference

- Learner comments on their ability to initiate and perform actions in IVR environment (Braun et al., 2018)
- Learner comments on their feeling of being ‘inside’ in the IVR environment (Lee, 2004)
- Learner talks about their ability to access information and to operate the IVR environment (Klepsch et al., 2017; Sweller, 2020)
- Learner talks about engaging with and processing the IVR learning content (Klepsch et al., 2017)

### Quantitative Results

**IVR Affordances**

<table>
<thead>
<tr>
<th></th>
<th>High Interactivity (n=33)</th>
<th>Limited Interactivity (n=33)</th>
<th>Mann-Whitney tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sense of agency</td>
<td>5.13 (1.04)</td>
<td>4.61 (1.23)</td>
<td>.11</td>
</tr>
<tr>
<td>Sense of presence (spatial)</td>
<td>5.77 (0.78)</td>
<td>6.00 (0.96)</td>
<td>.12</td>
</tr>
<tr>
<td>Sense of presence (control)</td>
<td>5.53 (0.82)</td>
<td>5.17 (1.24)</td>
<td>.14</td>
</tr>
</tbody>
</table>

No significant differences were found between treatments in sense of agency or sense of presence. Results were skewed towards the upper end of scale.
Qualitative Results

IVR Affordances

Quantitative Results

Cognitive Load

There was a significant difference between treatments in germane load ($p < 0.01$).

No significant difference was found in extraneous load. Results were heavily skewed towards the lower end of the scale.

Qualitative Results

Cognitive Load
AUTHOR INFORMATION

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ABSTRACT

Immersive virtual reality (IVR) has potential for increasing training engagement in many disciplines, including safety training. Nevertheless, its educational use remains detached from learning theory. We address this gap by asking what kind of pedagogical model supports IVR occupational safety training. The model we propose is theoretically based on simulation learning and IVR learning research. The model is being developed in design-based research and we have empirically tested it during training interventions. Data were collected from questionnaires, observations, video recordings and stimulated recall interviews, and were analysed using mixed methods. The results were used to develop the pedagogical model. They advance IVR learning theory and educational practise.
REFERENCES


Association for the Advancement of Computing in Education. https://www.learntechlib.org/p/222424/


SCREEN TIME