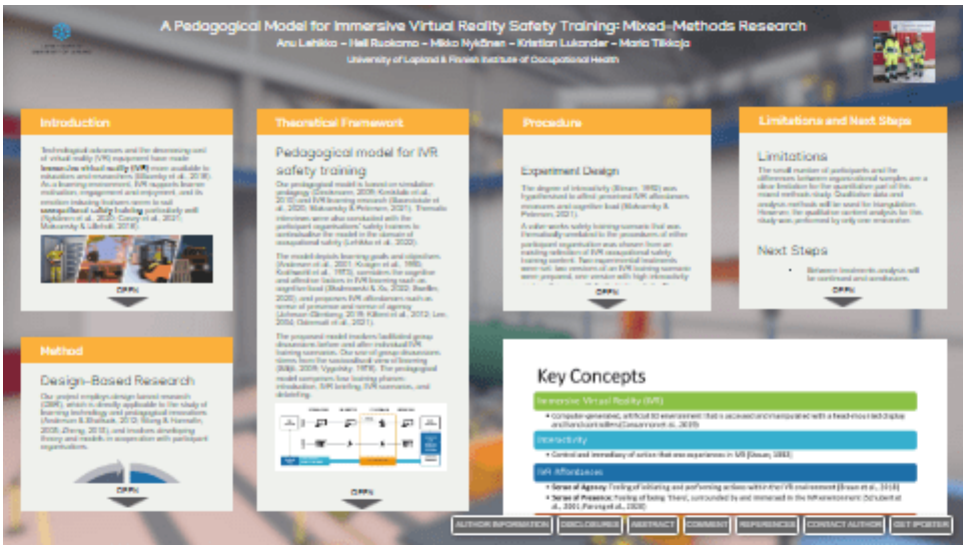
A Pedagogical Model for Immersive Virtual Reality Safety Training: Mixed-Methods Research



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PRESENTED AT:

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).

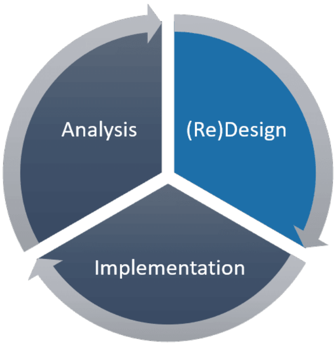
However, the role of cognitive and affective factors in IVR learning effectiveness is still unclear (e.g. Makransky et al., 2019). Furthermore, IVR research has remained disconnected from learning theories (Radhakrishnan et al., 2021; Radianti et al., 2020).

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?

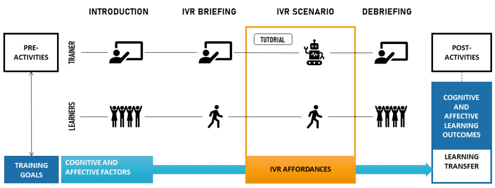
THEORETICAL FRAMEWORK

Pedagogical model for IVR safety training

Our pedagogical model is based on simulation pedagogy (Dieckmann, 2009; Keskitalo 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 questionnaireincluded 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] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1680176584/aera-2023/D4-F4-67-08-0A-1F-64-83-DD-D3-EC-E8-A8-2D-F8-E4/Video/2023-03-30_X-ray_screening_clips_ruqotk.mp4

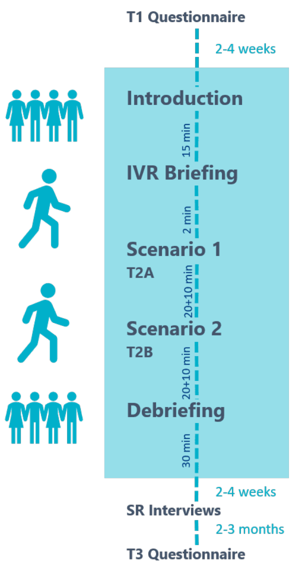
Video credit: FIOH/Virtuario

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

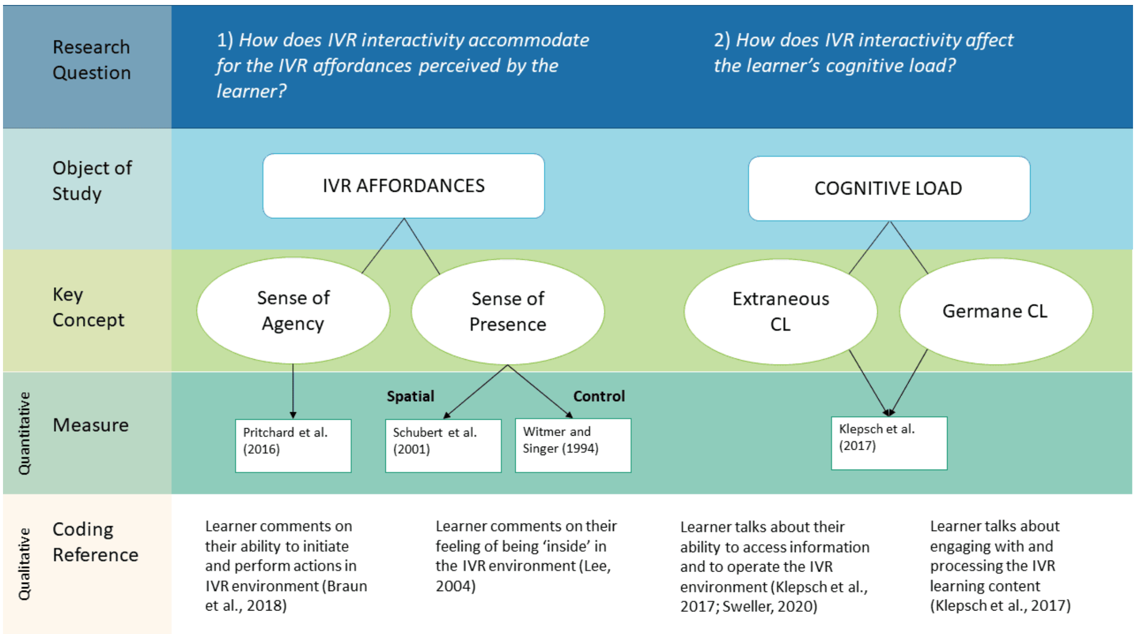
- Control and immediacy of action that one experiences in IVR (Steuer, 1992)

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)



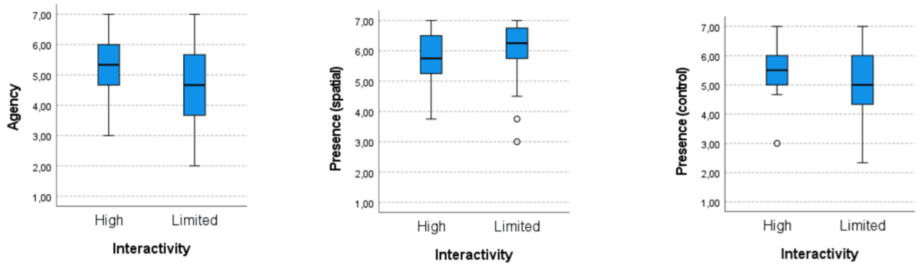
Quantitative Results

IVR Affordances

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

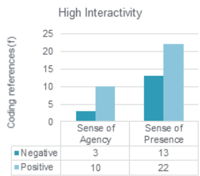
IVR Affordances	High Interactivity (n=33)	Limited Interactivity (n=35)	Mann-Whitney tests
	Mean (SD)	**Mean (SD)**	**p**
Sense of agency	5.13 (1.04)	4.61 (1.23)	.11
Sense of presence (spatial)	5.77 (0.78)	6.00 (0.96)	.12
Sense of presence (control)	5.53 (0.82)	5.17 (1.24)	.14

of the scale.



Qualitative Results

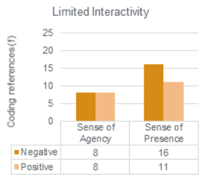
IVR Affordances



Treatment A

Sense of Agency and Sense of Presence in Treatment A Participants' Interviews

	Sense of Agency	Sense of Presence
Negative	- Scenario script imposed some limitations on interaction	- Sounds from other learners' HMDs were distracting; some learners felt they must hurry
Positive	+ Variety of tasks and actions were described, such as making safety checks before advancing to work site	+ Strong feeling of presence was described; moving and action added credibility to IVR experience



Treatment B

Sense of Agency and Sense of Presence in Treatment B Participants' Interviews

	Sense of Agency	Sense of Presence
Negative	- No opportunities to learn from mistakes - Interaction only with text boxes	- Sounds from other learners' HMDs were distracting; some learners felt they must hurry
Positive	+ Walking, pointing and clicking actions were described + Advancing at one's own pace + IVR responsiveness gave a feeling a being in control	+ Scenario felt authentic due to own movement and animations

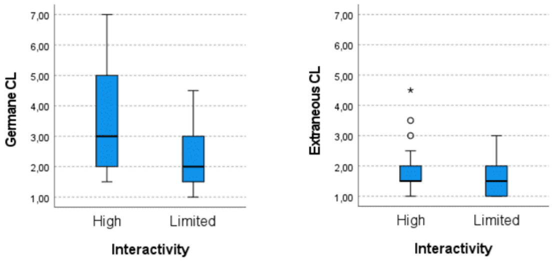
Quantitative Results

Cognitive Load

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

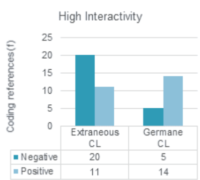
No significant difference was found in extraneous load. Results were heavily skewed towards the lower end of the scale.

Cognitive Load	High interactivity (n=33)	Limited interactivity (n=35)	Mann-Whitney tests
	Mean (SD)	Mean (SD)	p
Germane CL	3.46 (1.68)	2.31 (1.09)	<.01
Extraneous CL	1.84 (0.78)	1.51 (0.54)	.06



Qualitative Results

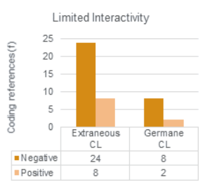
Cognitive Load



Treatment A

Extraneous and Germane Cognitive Load in Treatment A Participants' Interviews

	Extraneous CL	Germane CL
Negative	- Problems with object interaction - Lack of instructions	- Some learners described trying just to advance as quickly as possible
Positive	+ Good clarity of instruction + Alternating instructional text and learner activity + Combination of text and narration	+ Challenges and the ability to make mistakes increased engagement



Treatment B

Extraneous and Germane Cognitive Load in Treatment B Participants' Interviews

	Extraneous CL	Germane CL
Negative	- Difficulty in understanding instructions and carrying out actions to advance in scenario	- Scenario did not challenge the learners, little effort was needed to complete it
Positive	+ Simplicity and responsiveness of interface + Possibility to proceed at one's own pace	+ Some learners paused to reflect on learning content

	pace + Combination of text and narration	

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TRANSCRIPT

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

Anderson, L. W., & Krathwohl, D. R. (2001). A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. Longman.

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research? Educational Researcher, 41(1), 16–25.

Baceviciute, S., Mottelson, A., Terkildsen, T., & Makransky, G. (2020). Investigating representation of text and audio in educational VR using learning outcomes and EEG. In Proceedings of Conference on Human Factors in Computing Systems. https://doi.org/10.1145/3313831.3376872

Bandura, A. (1997). Self-efficacy: The exercise of control. W. H. Freeman/Times Books/Henry Holt & Co.

Bengtsson, M. (2016). How to plan and perform a qualitative study using content analysis. NursingPlus Open, 2(16), 8–14. https://doi.org/10.1016/j.npls.2016.01.001

Billett, S. (2021). Mediating worklife learning and the digitalisation of work. British Journal of Educational Technology, 52(4), 1580–1593. https://doi.org/10.1111/bjet.13115

Casey, T., Turner, N., Hu, X., & Bancroft, K. (2021). Making safety training stickier: A richer model of safety training engagement and transfer. Journal of Safety Research, 78, 303–313. https://doi.org/10.1016/j.jsr.2021.06.004

Concannon, B. J., Esmail, S., & Roduta Roberts, M. (2019). Head-mounted display virtual reality in post-secondary education and skill training. Frontiers in Education, 4, 1–23. https://doi:10.3389/feduc.2019.00080

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? British Journal of Educational Technology, 41(1), 10–32. https://doi.org/10.1111/j.1467-8535.2009.01038.x

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. Educational Research, 32, 5–8.

Dieckmann, P. (2009). Simulation settings for learning in acute medical care. In P. Dieckmann (Ed.), Using simulations for education, training and research (pp. 40–138). Pabst Science Publishers.

Dieckmann, P., & Ringsted, C. (2013). Simulation-based training in healthcare. In K. Forrest, J. McKimm, & S. Edgar (Eds.), Essential simulation in clinical education (pp. 43–58). John Wiley & Sons.

Elbamby, M. S., Perfecto, C., Bennis, M., & Doppler, K. (2018). Toward low-latency and ultra-reliable virtual reality. IEEE Network, 32(2), 78–84. https://doi:10.1109/MNET.2018.1700268

Eppich, W., & Cheng, A. (2015). Promoting excellence and reflective learning in simulation (pearls): Development and rationale for a blended approach to health care simulation debriefing. Simulation in Healthcare, 10(2), 106–115. https://doi.org/10.1097/SIH.0000000000000072

Feng, Q., Luo, H., Li, W., Chen, Y., & Zhang, J. (2021). The moderating effect of debriefing on learning outcomes of IVR-based instruction: An experimental research. Applied Sciences, 11(21), 10426. https://doi.org/10.3390/app112110426

Johnson-Glenberg, M. C. (2019). The necessary nine: Design principles for embodied VR and active stem education. In P. A. Díaz, A. Ioannou, K. Kumar Bhakat, & M. J. Spector (Eds.), Learning in a digital world. Smart computing and intelligence (pp. 83–112). Springer. https://doi.org/10.1007/978-981-13-8265-9_5

Kilteni, K., Groten, R., & Slater, M. (2012). The sense of embodiment in virtual reality. Presence: Teleoperators and Virtual Environments, 21(4), 373–387. https://doi.org/10.1162/pres_a_00124

Klepsch, M., Schmitz, F., & Seufert, T. (2017). Development and validation of two instruments measuring intrinsic, extraneous, and germane cognitive load. Frontiers in Psychology, 8, 2017. https://doi.org/10.3389/fpsyg.2017.01997

Kraiger, K., Ford, J. K., & Salas, E. (1993). Application of cognitive, skill-based, and affective theories of learning outcomes to new methods of training evaluation. Journal of Applied Psychology, 78(2), 311.

Krathwohl, D. R., Bloom, B. S., & Masia, B. B. (1973). Taxonomy of educational objectives: The classification of educational goals. Handbook II: Affective domain. Longman.

Lee, K. M. (2004). Presence, explicated. Communication Theory, 14(1), 27–50. https://doi.org/10.1111/j.1468-2885.2004.tb00302.x

Lehikko, A., Nykänen, M., & Ruokamo, H. (2023). Developing a pedagogical model for immersive virtual reality safety training: A discussion script to support learning transfer. In T. Cherner & A. Fegely (Eds.), Bridging the XR technology-to-practice gap (Vol 1., pp. 215-228). Association for the Advancement of Computing in Education. https://www.learntechlib.org/p/222242/

Lehikko, A., Ruokamo, H., & Nykänen, M. (2022). Developing a pedagogical model for immersive virtual reality in teaching and learning. In E. Langran (Ed.), Proceedings of Society for Information Technology & Teacher Education International Conference (pp. 1990-1994). https://www.learntechlib.org/primary/p/220982/

Makransky, G., & Lilleholt, L. (2018). A structural equation modeling investigation of the emotional value of immersive virtual reality in education. Educational Technology Research and Development, 66(5), 1141–1164. https://doi.org/10.1007/s11423-018-9581-2

Makransky, G., & Petersen, G. B. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. Educational Psychology Review, 33, 937–958. https://doi.org/10.1007/s10648-020-09586-2

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. Learning and Instruction, 60, 225–236. https://doi.org/10.1016/j.learninstruc. 2017.12.007

Metcalfe, J. (2017). Learning from errors. Annual Review of Psychology, 68, 465–489. https://doi.org/10.1146/annurev-psych-010416-044022

Meyer, O. A., Omdahl, M. K., & Makransky, G. (2019). Investigating the effect of pre-training when learning through immersive virtual reality and video: A media and methods experiment. Computers and Education, 140. https://doi.org/10.1016/j.compedu.2019.103603

Miguel-Alonso, I., Rodriguez-Garcia, B., Checa, D., & Bustillo, A. (2023). Countering the novelty effect: A tutorial for immersion virtual reality learning environments. Applied Sciences (Switzerland), 13(1), 593. https://doi.org/10.3390/app13010593

Nykänen, M., Puro, V., Tiikkaja, M., Kannisto, H., Lantto, E., Simpura, F., Uusitalo, J., Lukander, K., Räsänen, T., Heikkilä, T., & Teperi, A. (2020). Implementing and evaluating novel safety training methods for construction sector workers: Results of a randomized controlled trial. Journal of Safety Research, 75, 205–221. https://doi.org/https://doi.org/10.1016/j.jsr.2020.09.015

Parong, J., & Mayer, R. E. (2021). Cognitive and affective processes for learning science in immersive virtual reality. Journal of Computer Assisted Learning, 37(1), 226–241. https://doi.org/10.1111/jcal.12482

Parong, J., Pollard, K. A., Files, B. T., Oiknine, A. H., Sinatra, A. M., Moss, J. D., Passaro, A., & Khooshabeh, P. (2020). The mediating role of presence differs across types of spatial learning in immersive technologies. Computers in Human Behavior, 107, 106290. https://doi.org/10.1016/J.CHB.2020.106290

Pelargos, P. E., Nagasawa, D. T., Lagman, C., Tenn, S., Demos, J. V., Lee, S. J., Bui, T. T., Barnette, N. E., Bhatt, N. S., Ung, N., Bari, A., Martin, N. A., & Yang, I. (2017). Utilizing virtual and augmented reality for educational and clinical enhancements in neurosurgery. Journal of Clinical Neuroscience: Official Journal of the Neurosurgical Society of Australasia, 35, 1–4. https://doi:10.1016/j.jocn.2016.09.002

Polito, V., Barnier, A. J., & Woody, E. Z. (2013). Developing the Sense of Agency Rating Scale (SOARS): An empirical measure of agency disruption in hypnosis. Consciousness and Cognition, 22(3), 684–696. https://doi.org/10.1016/j.concog.2013.04.003

Pritchard, S. C., Zopf, R., Polito, V., Kaplan, D. M., & Williams, M.A. (2016). Non-hierarchical influence of visual form, touch, and position cues on embodiment, agency, and presence in virtual reality. Frontiers in Psychology, 7, 1649. https://doi.org/10.3389/fpsyg.2016.01649

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Computers & Education, 147, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Radhakrishnan, U., Koumaditis, K., & Chinello, F. (2021). A systematic review of immersive virtual reality for industrial skills training. Behaviour & Information Technology, 40(12), 1310–1339. https://doi.org/10.1080/0144929X.2021.1954693

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. American Psychologist, 55(1), 68–78

Schubert, T., Friedmann, F., & Regenbrecht, H. (2001). The experience of presence: Factor analytic insights. Presence: Teleoperators & Virtual Environments, 10(3), 266–281

Skulmowski, A., & Xu, K. M. (2022). Understanding cognitive load in digital and online learning: A new perspective on extraneous cognitive load. Educational Psychology Review, 34(1), 171–196. https://doi.org/10.1007/s10648-021-09624-7

Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. In F. Biocca & M. R. Levy (Eds.), Communication in the age of virtual reality (pp. 33–56). Lawrence Erlbaum Associates.

Sweller, J. (2020). Cognitive load theory and educational technology. Education Technology Research and Development, 68, 1–16. https://doi.org/10.1007/s11423-019-09701-3

Vygotsky, L. (1978). Mind in society. The development of higher psychological process. Harvard University Press.

Wang, F., & Hannafin, M. (2005). Design-based research and technology-enhanced learning environments. Educational Technology Research and Development, 53(4), 5–23.

Witmer, B.G., & Singer, M. J. (1994). Measuring presence in virtual environments. ARI Technical Report, Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Zheng, L. (2015). A systematic literature review of design-based research from 2004 to 2013. Journal of Computers in Education, 4(2), 399–420.

SCREEN TIME