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Doctoral Colloquium—How Interactivity and Presence Affect Learning in Immersive Virtual Reality: A Mixed Methods Study Design

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Abstract. This doctoral colloquium paper describes a mixed-methods study to investigate the impact of high interactivity Immersive Virtual Reality (iVR) materials on learning in higher education. It is motivated by the changing landscape of iVR technology and the need to develop pedagogic frameworks for its effective integration into higher education settings. The study will focus on the concepts of interactivity and presence, exploring their influence on learning outcomes and the learner's experience. The research questions address the relationship between interactivity, presence, and learning outcomes, with a specific focus on the impact of different levels of interactivity on feelings of presence and measures of learning, and the impact of interactivity and presence on cognitive load. The study will employ a mixed methods approach, combining quantitative surveys and qualitative interviews to capture a holistic understanding of the effects of the iVR intervention. The iVR experience material, a fully planned narratively structured interactive game designed to teach about the pH scale and how to conduct pH testing, has been developed in Unity for use with Meta Quest 2 headsets and touch controllers. The study is expected to contribute to the development of a framework for integrating iVR in higher education and a taxonomy of VR pedagogy and affordances.

Keywords: Reality, Interactivity, Presence, Higher Education, Pedagogy.

1 Introduction

There is a confusing landscape of terminology used to describe Immersive Virtual Reality (iVR) experiences and affordances, which must adapt with the capabilities of VR technology. What was 'immersive' five years ago is now eclipsed in terms of both technological ability and user experience, making it difficult to identify comparative research [1, 2].

There has been a shift in the affordances of the technological solutions incorporated into studies towards higher fidelity graphics, greater freedom of movement through more intuitive controllers and hand tracking. There has also been an increase in the number of studies that investigate the educational application of iVR and the introduction of consumer-grade standalone headsets such as the Oculus Quest in 2019 [3].

While iVR has been studied in a diverse range of contexts, including in K-12, post-secondary and higher education settings, there is often a lack of explicitly stated pedagogic design in the interventions used [2], and most existing theories of learning do not incorporate the specific affordances of iVR. The extension and validation of learning theory to include iVR is therefore a priority [2, 4]. It has also been suggested that iVR educational experiences can have negative impacts on learning through increased cognitive load [5, 6].

Some researchers have proposed new or extended pedagogic approaches to include iVR [4, 7-10], for example, building on work on cognitive load theory [11], multimedia learning and generative learning [12] that were developed for more traditional teaching methods and media. All seek to model how the affordances of iVR interact with other aspects of the learning process, how they can best be scaffolded, and how they impact on measured learning outcomes.

The core affordances of iVR include immersion, presence, embodiment, interactivity and agency [2, 8]. The user's experience of iVR will be mediated by the format of the VR experience – the specific technological and software attributes available in the iVR material that support these core affordances. Immersion and presence have been studied repeatedly, but the level of interactivity available to the participants varies widely [1] and does not often take full advantage of the capabilities of modern VR systems. This makes classifying iVR experiences between studies difficult; for example, studies focusing on the impact of interactivity have different conceptualisations of what is 'interactive' and 'highly interactive'. Petersen et al. [8] included a 'highly immersive, low interactive' condition that used a pre-determined path through a virtual museum and its exhibits, while their 'highly immersive, highly interactive' condition allowed users to walk through the same museum space and initiate presentations for themselves. Pavic et al. [1] conducted a review that showed that the word 'interactive' could be said to mean 'able to navigate' or 'able to complete a task'. These varying definitions offer a very different user experience.

In the context of traditional computer-based learning, Domagk et al. [13] argue that interactivity requires a reciprocal exchange between at least two participants (one of which may be the learning material as a proxy teacher). Lindgren & Johnson-Glenberg consider that learner retention may also be enhanced through the congruity between action and response, but educational interventions must be "designed such that they engineer the desired instances of understanding" [14, p. 448]. Johnson-Glenberg et al. [15] propose a three-pronged taxonomy wherein embodied learning requires a combination of sensorimotor engagement, gestural congruence and a sense of immersion in the learner.

It is difficult to argue that the definition of 'highly interactive' in the example provided by Petersen et al. [8] meets this definition. While their overall results suggest that both immersion and interactivity do have a positive relationship to physical presence, an unexpected negative relationship between user reported perceptions of embodiment and learning outcome led them to suggest that low congruence between interaction method and learning material could be responsible, thus suggesting a research gap in investigating iVR simulations specifically designed to promote embodied learning. Johnson-Glenberg et al. [16] studied high versus low interactivity in an educational game that was optimised for both presence and embodiment, which showed increased retention in the high-interactivity high-agency condition. However, their study did not use fully congruent or complex interactions and used less immersive Oculus Go headsets.

2 Research Questions

The focus of my doctoral research will be the development of a framework for the design and integration of iVR in higher education contexts, and a taxonomy of VR pedagogy. This study seeks to address the research gap identified here by focusing on congruent, high-level interactivity consistent with the capabilities of currently available mass-market VR headsets.

The research questions the study addresses are:

1. Do increased levels of interactivity result in greater feelings of presence in an iVR learning environment compared to a lower interactivity intervention?
2. Do feelings of presence correlate positively with learning outcomes?
3. How do interactivity and presence impact the learner's experience?

Participants will be randomly assigned to experience one of two conditions. The high-interactive condition will allow for meaningful interaction with objects in the virtual world, and their actions will impact on the pacing and the responses they receive during the experience. The low-level interactivity condition will allow users to experience the virtual environment by looking at items and initiating and controlling material presentation, however they will not be able to interact with the virtual environment in a congruent manner.

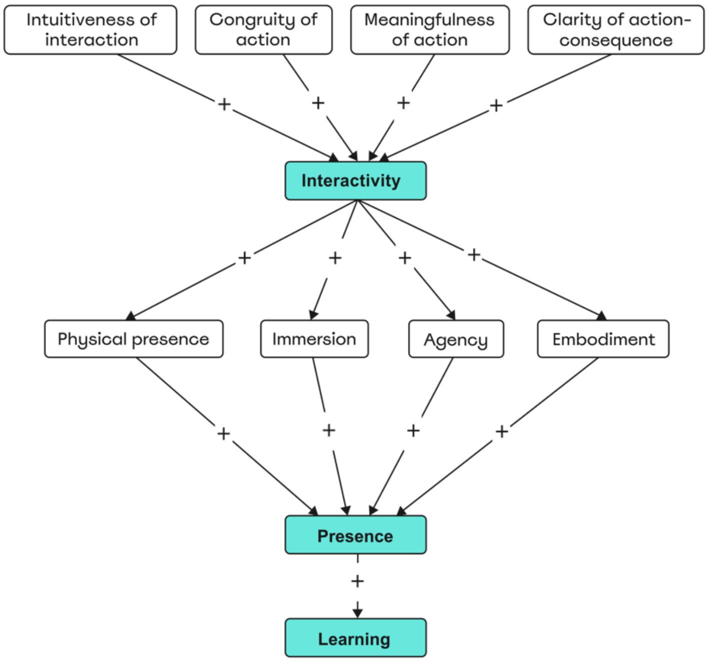

Fig. 1. Conceptual map of the elements of interactivity and presence, and hypothesised impact on learning.

3 Conceptual Frameworks

3.1 Interactivity and Presence

In the context of this study, interactivity and presence are conceptualised as amalgamations of different components (see Fig. 1). Interactivity, the ability of a user to act within the virtual environment, comprises intuitiveness of interaction, congruity and meaningfulness of action and clarity of action/consequence [14, 17-18]. Presence, the sense a user has of being inside and part of the virtual world, comprises four elements of iVR experience: feelings of physical presence, immersion, agency and embodiment [16-20]. Each aspect of this conceptualisation is interconnected, having the effect of enhancing or supporting the other feelings, or capable of undermining them through poor implementation or technical problems. Presence is a result of an active decision by the user to lend their attention toward the virtual world at the expense of the physical. Increased attentional involvement feeds into feelings of presence [17], such that the success of iVR is a partnership between the technology, the learning design and the learner.

3.2 Hypotheses

There are three hypotheses related to this conceptualization:
H1: Highly interactive content will have a positive effect on presence
H2: Highly interactive content will have a negative effect on extraneous environmental cognitive load
H3: Self-reported feelings of presence will have a positive effect on learning outcomes.

If H1 and H3 are supported, a positive relationship exists between high-level interactivity, presence and learning outcomes, supporting the conceptualization of presence described in section 3.1. This would have implications for the practical design of iVR educational interventions. Presence is an inherently subjective measure (see [4, 6, 8, 21, 22] for examples), and if it is possible to design for interactivity as a proxy for influencing presence, then this would provide a useful way to optimize learning materials for presence or manipulate the levels of presence felt by learners according to a desired level.

If H2 is supported, it would suggest that with careful design and a focus on interactivity, some of the cognitively overwhelming elements of iVR (e.g. high environmental fidelity and presence, and the use of on-screen text) suggested by Makransky et al. [5] and Ahn et al. [6] could be managed, supporting measured learning.

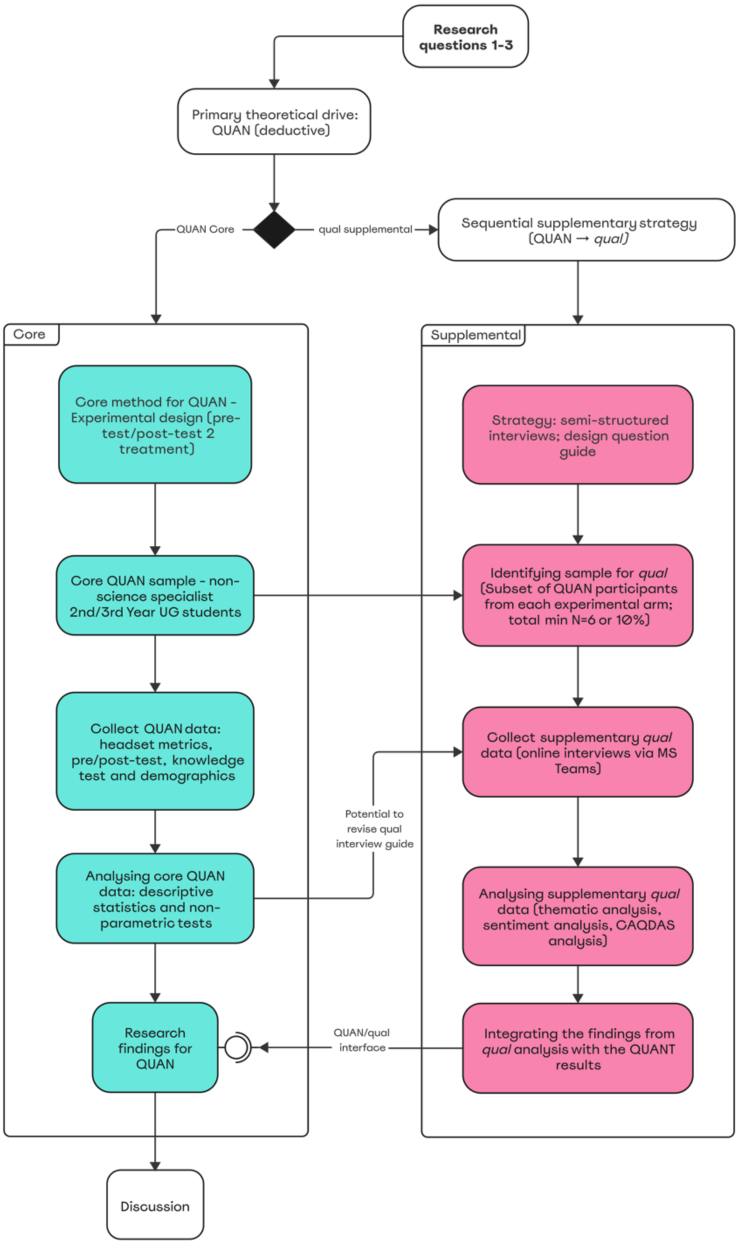

Fig. 2. Mixed Methods Research Design, adapted from Morse [25].

4 Research Design and Experimental Protocol

4.1 Research Design

This study uses a mixed methods approach, which is appropriate both to the expected small sample size and to capture valuable additional depth that can help expand the findings of the quantitative component [23-24]. Fig. 2 provides an overview of the research approach. Radianti et al. [2] argue for the use of mixed methods approaches to evidence the holistic effects of iVR interventions, while finding in their review that qualitative data was captured in only 4 of 38 articles.

The overall research programme is devoted to iVR in higher education. The target population for this research is therefore post-secondary students, with participants recruited from the 2nd and 3rd year Durham University student population through advertising via student communications bulletins, with the exclusion of chemistry and related speciality students from the science faculty. This will prevent those with specialist knowledge of the learning material from distorting the results. A screening questionnaire will be completed by all participants in advance of being accepted onto the full study. The screening tool will assess participants' accessibility needs, previous VR experience, and susceptibility to motion sickness.

4.2 Experimental Protocol

An overview of the experimental protocol can be seen in Fig. 3. Participants will be unaware of the existence of the alternate condition they are assigned to.

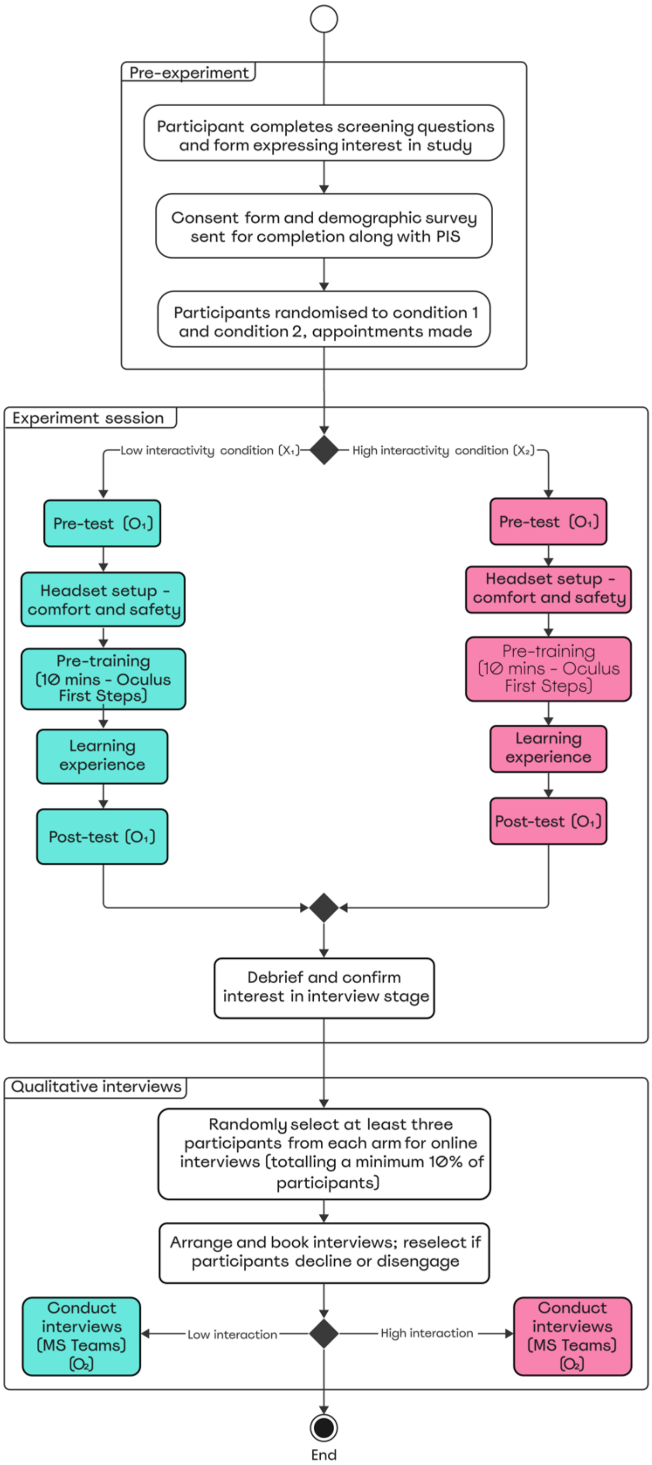

Fig.3. Experimental protocol.

4.3 Survey and Interview Instruments

A range of adapted validated quantitative survey instruments will be used to assess the user's experience of Agency [25], Physical Presence [26], Intrinsic Motivation [27], Self-efficacy [28, 29], Extraneous Cognitive Load (Interaction) and Extraneous Cognitive Load (Environment) [21], Situational Interest [18] and Embodied Learning [30]. The original papers related to each set of questions have been reviewed. Some questions have also been rebalanced to address the potential for agreement bias. Knowledge-based pre- and post-tests will be written to assess learning gain appropriate to the final intervention.

Cybersickness is a recognised risk of iVR and can cause symptoms akin to motion sickness in those who are susceptible. These symptoms can range from mild discomfort to temporarily debilitating. Questions from the shortened Motion Sickness Susceptibility Questionnaire (MSSQ-Short) [31] will be included in the pre-experiment screening survey to exclude those at significant risk of experiencing symptoms. Additionally, since cybersickness symptoms may also impact on both cognitive engagement and performance [32], assessment of the users' experience of cybersickness during the experiment will be made using the Cybersickness in Virtual Reality Questionnaire (CSQ-VR) [32], which has been validated against existing simulator sickness instruments.

A demographic survey, experimental notes and a semi-structured interview guide will also be used. The interview guide is structured around the participant's experience, their perceptions of interactivity and presence, the impact they feel the VR experience had on learning, and overall impressions of the VR experience. Interviews will be conducted via online video conferencing, including video and transcript recording. Transcripts will be corrected using the video to ensure accuracy. The qualitative data will be analysed using thematic analysis [33] to discover themes, patterns and concepts within the data. ATLAS.ti Computer-Aided Qualitative Data Analysis (CAQDAS) software will be used to support the thematic analysis process.

Qualitative and quantitative data will be synthesised during the write-up of the results and discussion to produce a full picture of the data.

4.4 Limitations

While the study aims to investigate the impact of high interactivity Immersive Virtual Reality (iVR) materials on learning in higher education, it has some limitations. Firstly, the study focuses on specific subject matter, the pH scale and how to conduct pH testing, which may limit the generalisability of the results to other subject areas. Secondly, the study is conducted with a specific small sample, post-secondary students from Durham University, which may limit the applicability of the results to other populations. Additionally, the study uses a specific iVR technology, the Meta Quest 2 headset and touch controllers, which may limit the generalisability of the results to other current or future iVR technologies and interaction methods, such as hand tracking.

4.5 iVR Experience Material

The material for the iVR experience is a fully planned narratively structured interactive game designed to teach about the pH scale and how to conduct pH testing. This was selected in consultation with an associate professor in chemistry as an appropriate subject for the length of the experimental session, and for a level of material that non-specialist students would be expected to have incomplete knowledge of.

The game is being developed in Unity and will be used in conjunction with Meta Quest 2 headsets and touch controllers. Once the high-interactive game development is complete, the low-interactive version will be adapted from it. A development blog and progress videos are available at www.nicolafern.com, and example screen captures can be seen in Fig. 4-6.

This interactive game can be reformatted and manipulated to be suitable for use in future studies investigating other aspects related to iVR education research.

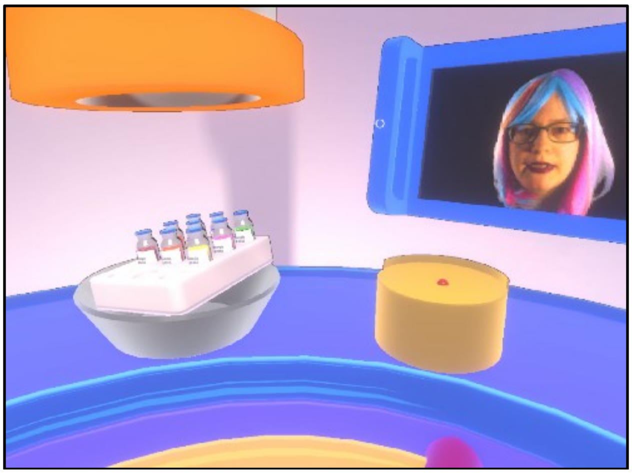

Fig.4. Orientation scene with character.

Fig.5. Basic pH testing activity.

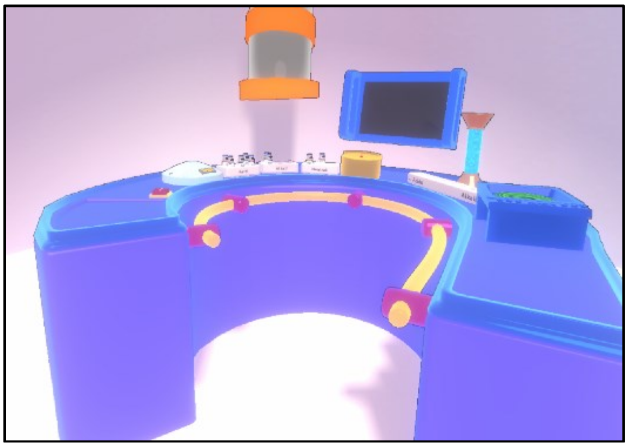

Fig.6. Complete work area for precise pH testing activity.

5 Conclusion

This paper has drawn a clear line through the existing literature to expose a research gap – assessing the impact of interactive iVR materials for higher education that incorporate congruent, high-fidelity interaction. It outlines an empirical study to probe for further knowledge. It is expected that this study would be the first in a series of investigations to test and further develop both the conceptualisation outlined in Fig. 1 and begin to define a framework for integrating iVR in higher education. Future work will develop the ideas that emerge from the study, particularly focusing on optimising interactivity for learning and developing a set of guidelines and game mechanics for educational VR development, while being open to avenues indicated by any surprising results. I would also like to conduct studies exploring educational VR in the curriculum context, and an ongoing development project is expected to provide opportunities to pursue these ideas in teaching materials used in live undergraduate modules.

Acknowledgements

Figures 1-3 previously published by Nicola Fern under a CC-BY-SA Creative Commons Licence at: https://www.nicolafern.com/publications-presentations/poster-session-pgr-conference-2023/

References

1. Pavic, K., Vergilino-Perez, D., Gricourt, T., Chaby, L.: Because I'm happy — an overview on fostering positive emotions through Virtual Reality. Frontiers in Virtual Reality 3 (2022). https://doi.org/10.3389/frvir.2022.788820
2. Radianti, J., Majchrzak, T. A., Fromm, J., Wohlgenannt, I.: A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Computers & Education 147 (2020). https://doi.org/10.1016/j.compedu.2019.103778
3. Pellas, N., Mystakidis, S., Kazanidis, I.: Immersive Virtual Reality in K-12 and Higher Education: A systematic review of the last decade scientific literature. Virtual Reality 25(3), 835–861 (2021). https://doi.org/10.1007/s10055-020-00489-9
4. Huang, W., Roscoe, R. D., Craig, S. D., Johnson-Glenberg, M. C.: Extending the Cognitive-Affective Theory of Learning with Media in Virtual Reality Learning: A Structural Equation Modeling Approach. Journal of Educational Computing Research 60(4), 807–842 (2022). https://doi.org/10.1177/07356331211053630
5. Makransky, G., Terkildsen, T. S., Mayer, R. E.: Adding immersive virtual reality to a science lab simulation causes more presence but less learning. Learning and Instruction 60, 225–236 (2019). https://doi.org/10.1016/j.learninstruc.2017.12.007
6. Ahn, S. J. (grace), Nowak, K. L., Bailenson, J. N.: Unintended consequences of spatial presence on learning in virtual reality. Computers & Education 186, 104532 (2022). https://doi.org/10.1016/j.compedu.2022.104532
7. Makransky, G., Petersen, G. B.: The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality. Educational Psychology Review 33(3), 937–958 (2021). https://doi.org/10.1007/s10648-020-09586-2
8. Petersen, G. B., Petkakis, G., Makransky, G.: A study of how immersion and interactivity drive VR learning. Computers & Education 179, 104429 (2022). https://doi.org/10.1016/j.compedu.2021.104429
9. Petersen, G. B., Stenberdt, V., Mayer, R. E., Makransky, G.: Collaborative generative learning activities in immersive virtual reality increase learning. Computers & Education 104931 (2023). https://doi.org/10.1016/j.compedu.2023.104931
10. Klingenberg, S., Jørgensen, M. L. M., Dandanell, G., Skriver, K., Mottelson, A., Makransky, G.: Investigating the effect of teaching as a generative learning strategy when learning through desktop and immersive VR: A media and methods experiment. British Journal of Educational Technology 51(6), 2115–2138 (2020). https://doi.org/10.1111/bjet.13029
11. Chandler, P., Sweller, J.: Cognitive Load Theory and the Format of Instruction. Cognition and Instruction 8(4), 293–332 (1991). https://doi.org/10.1207/s1532690xci0804_2
12. Mayer, R. E.: Multimedia learning. 3rd ed. Cambridge University Press, Cambridge (2021).
13. Domagk, S., Schwartz, R. N., Plass, J. L.: Interactivity in multimedia learning: An integrated model. Computers in Human Behavior 26(5), 1024–1033 (2010). https://doi.org/10.1016/j.chb.2010.03.003
14. Lindgren, R., Johnson-Glenberg, M.: Emboldened by Embodiment: Six Precepts for Research on Embodied Learning and Mixed Reality. Educational Researcher 42(8), 445–452 (2013). https://doi.org/10.3102/0013189X13511661
15. Johnson-Glenberg, M. C., Megowan-Romanowicz, C., Birchfield, D. A., Savio-Ramos, C.: Effects of Embodied Learning and Digital Platform on the Retention of Physics Content: Centripetal Force. Frontiers in Psychology 7 (2016). https://doi.org/10.3389/fpsyg.2016.01819
16. Johnson-Glenberg, M. C., Ly, V., Su, M., Zavala, R. N., Bartolomeo, H., Kalina, E.: Embodied Agentic STEM Education: Effects of 3D VR Compared to 2D PC. In: 2020 6th International Conference of the Immersive Learning Research Network (iLRN), pp. 24–30 (2020). https://doi.org/10.23919/iLRN47897.2020.9155155
17. Witmer, B. G., Singer, M. J.: Measuring Presence in Virtual Environments: A Presence Questionnaire. Presence: Teleoperators and Virtual Environments 7(3), 225–240 (1998). https://doi.org/10.1162/105474698565686
18. Knogler, M., Harackiewicz, J. M., Gegenfurtner, A., Lewalter, D.: How situational is situational interest? Investigating the longitudinal structure of situational interest. Contemporary Educational Psychology 43, 39–50 (2015). https://doi.org/10.1016/j.cedpsych.2015.08.004
19. Herrera, G., Jordan, R., Vera, L.: Agency and Presence: A Common Dependence on Subjectivity? Presence: Teleoperators and Virtual Environments 15(5), 539–552 (2006). https://doi.org/10.1162/pres.15.5.539

20. Johnson-Glenberg, M. C.: Immersive VR and Education: Embodied Design Principles That Include Gesture and Hand Controls. Frontiers in Robotics and AI 5 (2018). https://doi.org/10.3389/frobt.2018.00081
21. Andersen, M. S., Makransky, G.: The validation and further development of a multidimensional cognitive load scale for virtual environments. Journal of Computer Assisted Learning 37(1), 183–196 (2021). https://doi.org/10.1111/jcal.12478
22. Dubovi, I.: Cognitive and emotional engagement while learning with VR: The perspective of multimodal methodology. Computers & Education 183, 104495 (2022). https://doi.org/10.1016/j.compedu.2022.104495
23. Biesta, G.: Mixing Methods in Educational Research. In: Coe, R., Waring, M., Hedges, L., Day Ashley, L. (eds.) Research Methods and Methodologies in Education, 3rd ed. SAGE Publications (2021).
24. Morse, J.: Procedures and Practice of Mixed Method Design: Maintaining Control, Rigor, and Complexity. In: Tashakkori, A., Teddlie, C. (eds.) SAGE Handbook of Mixed Methods in Social & Behavioral Research, 2nd ed. SAGE, Thousand Oaks (2010).
25. Polito, V., Barnier, A. J., Woody, E. Z.: Developing the Sense of Agency Rating Scale (SOARS): An empirical measure of agency disruption in hypnosis. Consciousness and Cognition 22(3), 684–696 (2013). https://doi.org/10.1016/j.concog.2013.04.003
26. Makransky, G., Lilleholt, L., Aaby, A.: Development and validation of the Multimodal Presence Scale for virtual reality environments: A confirmatory factor analysis and item response theory approach. Computers in Human Behavior 72, 276–285 (2017). https://doi.org/10.1016/j.chb.2017.02.066
27. Makransky, G., Petersen, G. B.: Investigating the process of learning with desktop virtual reality: A structural equation modeling approach. Computers & Education 134, 15–30 (2019). https://doi.org/10.1016/j.compedu.2019.02.002
28. Meyer, O. A., Omdahl, M. K., Makransky, G.: Investigating the effect of pre-training when learning through immersive virtual reality and video: A media and methods experiment. Computers & Education 140, 103603 (2019). https://doi.org/10.1016/j.compedu.2019.103603
29. Pintrich, P. R., Smith, D. A. F., Garcia, T., McKeachie, W. J.: A Manual for the Use of the Motivated Strategies for Learning Questionnaire (MSLQ)