From spatial to platial – the role and future of immersive technologies in the spatial sciences

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Abstract: Immersive technologies such as virtual and augmented reality have been part of the technology mindset in computer and geospatial sciences since early on. The promise of delivering realistic experiences to the human senses that are not bound by physical reality has inspired generations of scientists and entrepreneurs alike. However, the vision for immersive experiences has been in stark contrast to the technology that has yet to properly support that vision; the community has battled nuisances such as cybersickness, tethers, and display quality for the last few decades. With the "final wave" of immersive technologies, we are now able to fulfill a long-held promise and freely envision how immersive technologies change spatial sciences by creating embodied experiences for geospatial applications. These experiences are not restricted by time or place, nor are they limited to the physical world. This contribution envisions a future for spatial sciences that is enabled by immersive technologies discussing their potential and challenges.

1 Introduction and background

The societal relevance of immersive technologies is increasing rapidly. For decades, high-end human-computer interaction labs and sophisticated training simulators have demonstrated the value of immersive technologies for basic research on humans' behavioral responses to environmental characteristics [5,68] and training environments, for example, in aviation and the military [45]. Current developments allow for immersive technologies to

enter the mainstream and substantially expand their role in research, education, communication, and decision-making across the academic spectrum and a plethora of societally relevant issues. Immersive technologies can increase educational equity by providing access to high-end training or field sites at scale [28, 40], they are natural environment for representing three-dimensional data [8], and are medium for visceral communication of climate change and its effects [23]. Immersive technologies have proven to facilitate learning languages [35], teach people how to make better choices in what they eat [10], and create empathy in people toward those less fortunate [1]. Immersive technologies are not a silver bullet to solve all of society's grand challenges, but they offer potential solutions worthy of exploring, especially for the spatial sciences.

"Immersive technologies" is an umbrella term for devices that deliver augmented, mixed, or virtual reality experiences. Researchers and industris may also use the terms XR, eXtended, or Cross-Realities when referring to immersive technologies (see Figure 1 for a visualization of [42]'s virtuality continuum). Augmented reality is defined as digital content superimposed onto the real world [62] [21], while virtual reality is defined as an experience without any access to our physical reality [4] [25]. Depending on the literature, mixed reality is either an advanced version of augmented reality that allows for tailored, three-dimensional integration of physical and virtual realities, or an umbrella term for all experiences that combine virtual and physical content [44] [42]. In case a virtual reality environment is experienced through a head-mounted display or cave, we use the term iVR to stress the immersive nature of the experience. There has been substantial debate and confusion about the terminology. I will briefly address some issues below, as clarifying any underlying concepts is essential for advancing the science of immersive experiences, including in the geospatial domain.
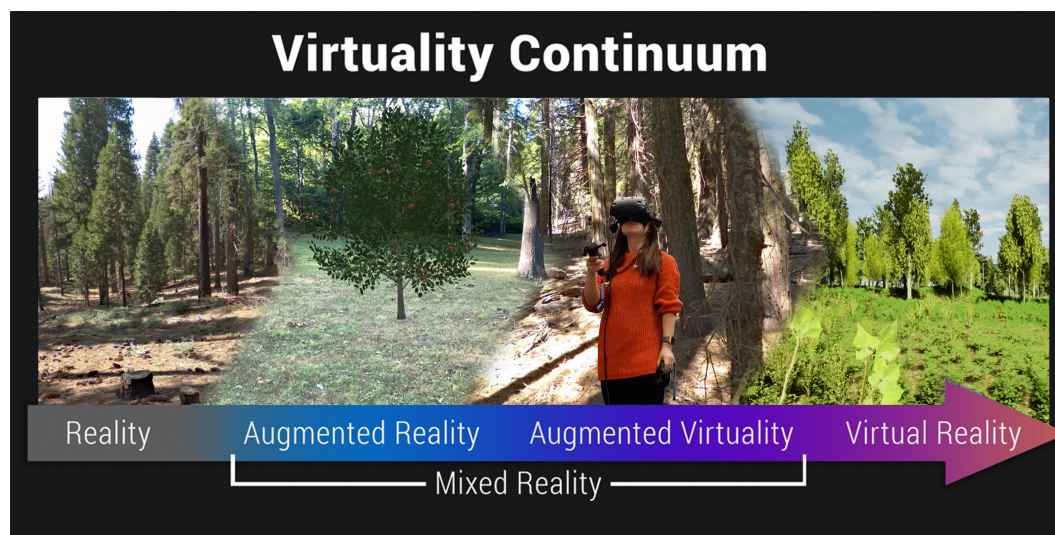

Figure 1: The figures shows a visualization of the virtuality continuum by [42]. (Image credit: Mark Simpson and Erica Krieger.)

2 Critical concepts of immersive technologies and experiences

Immersion and *presence* are key terms to characterize immersive technologies and user experiences enabled by them. There is, however, unfortunate confusion regarding the meaning of these terms to the extent that not only different but opposite definitions exist [6,16,58,65]. It is insightful to look into the etymology of immersion as it reveals the conundrum (see below). The definition of the verb *immerse* shows that the original meaning of immersion describes an object plunged into a liquid. This sense of the term immersion is the basis for defining immersive technologies. It focuses on the hardware, which is a medium that caters to the human senses in the same way that our physical reality immerses the human body. Hence, a head-mounted display is more immersive than a desktop computer, and a system with a haptic suit is more immersive than one relying on hand controllers only.

> **immerse** (v.)   "to plunge into (a fluid)," early 15c.   (implied in immersed), from Latin immersus, past participle of immergere "to plunge in, dip into, sink, submerge" (see immersion). Figuratively, of study, work, passion, etc., from the 1660s. Related: Immersed; immersing; immersive. https://www.etymonline.com/word/immerse

For the last 340 years, immersion has figuratively refered to the state of mind of the user, not the hardware. From this perspective, we can immerse ourselves in a book without becoming physically part of it. Many researchers have suggested using the term *presence* [58] or *spatial presence* for the user's response to the system and the design characteristics of the experience. Ijsselstein [24] saw presence as an experiential counterpart of immersion (see [64]), meaning that a system with highly immersive qualities will create a high sense of spatial presence, the feeling of "being there." The topic is complicated. Not only the system characteristics lead to a user's response, but several design characteristics of the entire immersive experience. And, not all aspects of the experience are exclusive to immersive technologies. Within the user-realm and their responses to an immersive system, we can define at least four essential concepts (see also [20,24,58,64]):

- **Sense of (spatial) presence** refers to the "sense of being there" (an alternative term is telepresence). The idea of *embodiment* is closely related to this term [24,58].
- **Co-presence or social presence** describes the connection that a user may develop toward other characters (AI or human) and the social context of said experience [3].
- **Flow** describes a user's engagement with the mechanics, challenges, and rules of an experience [14,55].
- **Narrative/sequential immersion** refers to a user's investment in a story and their engagement with the sequence of events. This is similar to reading a book. In an immersive experience, the progression can be manifold, meaning it can use elements such as an evolving gameplay or the exploration of new places to keep the player engaged [20,48].

I am not advocating for a specific terminology for the concepts outlined above but have summarized them in Figure 2 as a schematic. Most researchers agree on the concepts but profoundly disagree on the terminology. It is important to note that there is a distinct lack of literature in the spatial sciences on these concepts and how they influence research,

education, and decision-making in geospatial applications. Not all aspects of immersive experiences (see Figure 2) are equally relevant to the spatial sciences because they originate in other disciplines, such as serious games and media effects [12, 41, 49]. However, it is essential to create an awareness of all aspects of immersive technologies and experiences to envision their future in the spatial sciences.
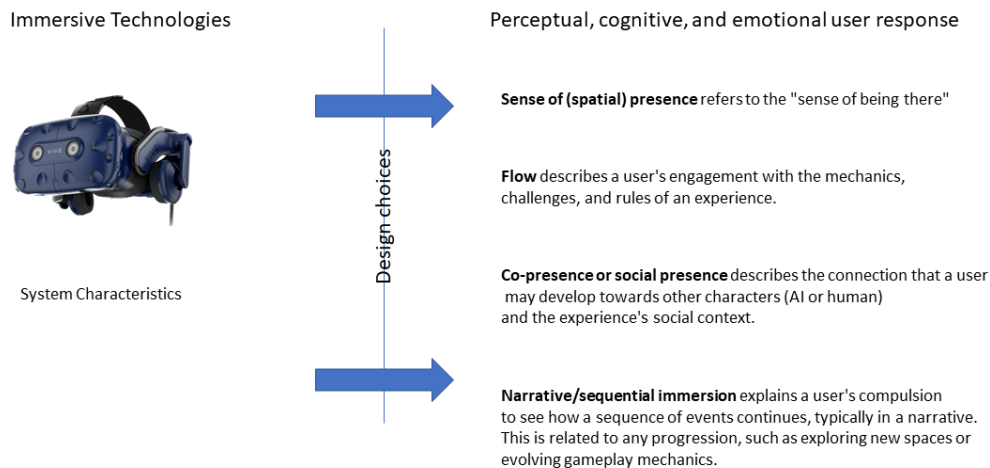

Figure 2: A schematic that shows critical concepts of immersive experiences (see discussion above). There is an unfortunate abundance of terminological confusion. It is important to separate the characteristics of the system from the user responses to a combination of system characteristics and design choices. While there are unique characteristics of immersive technologies the user responses are not restricted to a specific system. They could, for example, describe a user's response to a traditional desktop VR experience, not only immersive VR experiences.

3   From spatial to platial

To fully embrace the paradigmatic changes that immersive technologies offer for spatial sciences, it is essential to revisit their affordances [19], which are directly related to the above concepts and terminological clarifications. The focus here will be on immersive technologies and not the broader concept of virtual reality.

Immersive technologies allow a user to become part of a representation and quite literally step into one's data [4, 51]. The dichotomy that has existed ever since the first computers, of the user on one side and the system on the other, disappears in immersive technologies. Stepping into the representation itself paradigmatically changes we interact with data and subsequently our understanding of data. This transformative change happens on two levels. First, instead of representing data on two-dimensional surfaces, we provide a natural environment for three-dimensional data. Simpson [56] referred to this change as "3D-on-3D" compared to "3D-on-2D". Implications for understanding data are far-reaching,

including representing data at scale and using motion parallax for depth cues [26]. Second, stepping into a representation also turns data into an embodied experience. Instead of communicating abstractly, we can access data representations through several senses and potentially create a more emotional response. We connect to data not only by visually interpreting their representations but also through a visceral experience that creates a sense of being there.

This sense of spatial presence is a distinct and obvious advantage for creating realistic representation of physical reality as immersive experiences can replicate (almost) all aspects of a *place*, which is one of the core concepts of the geo-spatial and earth sciences [13, 53]. Psychologists have long been discussing the concept of *psychological distance* and how it challenges, for example, our ability to communicate climate change as a temporally and spatially remote event [59, 60]. With immersive experiences, we can reduce the psychological distance to places, both physically and temporally, and create a platform for grounding understanding and decision-making in actual experiences. Scientists have been given a tool that allows them to viscerally communicate changes in natural and built environments and connect them to what a landscape, such as a forest could look and feel like under different climate change scenarios [23, 54]; (see Figure 3 for an example).

Immersive experiences also change how users understand abstract data through an embodied experience [9, 33, 57]. Instead of indirectly manipulating objects smaller than the human body on computer screens, users are afforded a natural first-person perspective. This allows them to explore data in the same embodied way they would explore physical reality. The desktop metaphor is becoming substantially less abstract, and we are only at the beginning of fully comprehending the potential of *immersive analytics* [18, 33, 66].

Theoretical foundations for immersive experiences have been developed in several disciplines. For example, thinking of cognition as being grounded through embodied experiences has become an influential movement in the cognitive sciences [2, 63]. Embodiment is also a critical component of prominent learning theories, such as constructivism [47, 61]. Looking into the roots geospatial sciences, we intuitively understand the importance of an embodied, platial experience for both education and research [13, 52]. The turn toward understanding the role of embodiment in human cognition has, in fact, contributed to the scientific foundations of the spatial sciences [32]. With immersive technologies that allow for an embodied experience of data from places in the past, present, and future, and that turn abstract data into place-like experiences, we are at a turning point for how we conceptualize research, education, communication, and decision-making for geospatial applications [15, 22, 30].

4 A tiny research agenda

The geospatial sciences are in an excellent position to embrace immersive technologies. For several years, the ability to efficiently create three-dimensional representations of physical environments, existing or planned, has evolved rapidly [7, 11, 36–38]. We are witnessing tremendous developments in our ability to sense phenomena on earth through remote and photogrammetric approaches. We are also seeing modeling approaches that efficiently create three-dimensional data, turning abstract data spaces into potential candidates for visceral experiences [43].
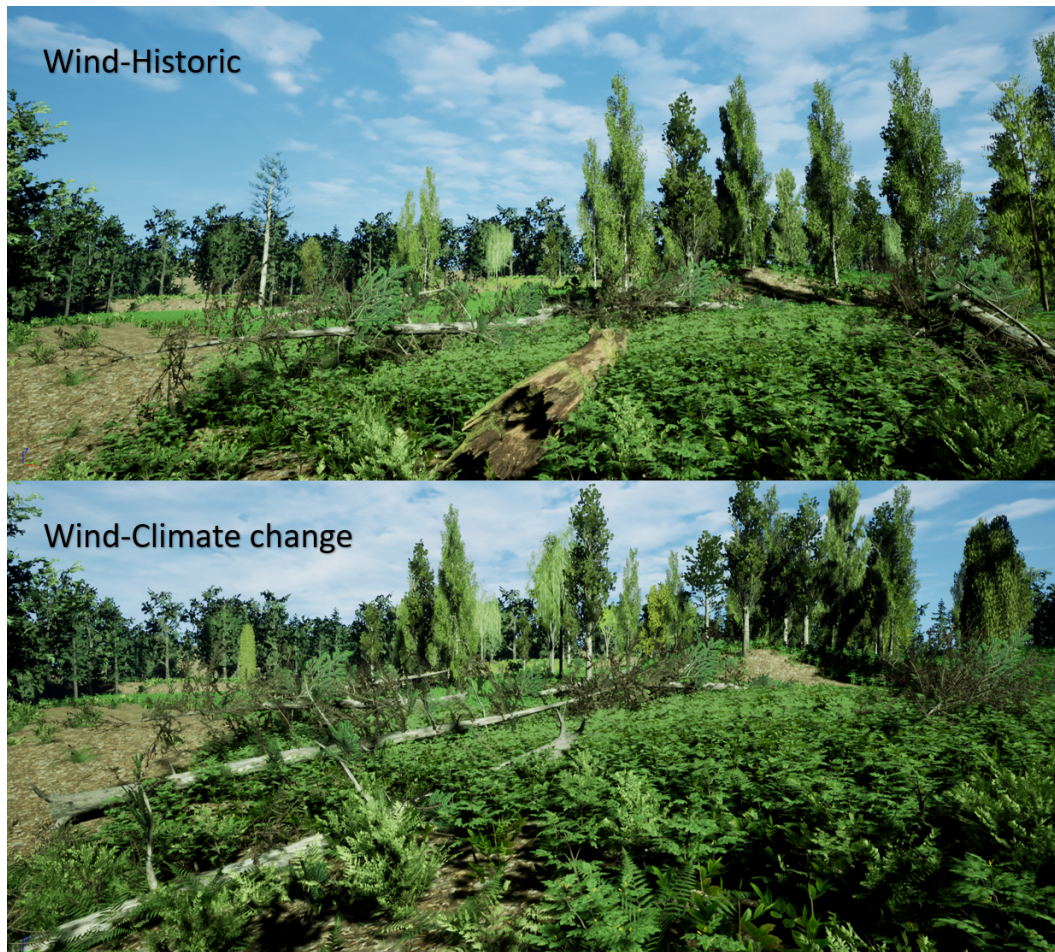
Figure 3: Forests are increasingly under stress from biotic and abiotic disturbances, including insects, windthrow, and climate. Among them, wind is a major ecological disturbance. We used a spatially-explicit, forest simulation model (LANDIS-II) to simulate how windstorms and climate change affect forest succession in 50 years into the future and developed a procedural modeling based workflow to create visceral experiences of different scenarios [23].

However, as much excitement as there is surrounding immersive technologies, we can also state with certainty that simply putting on a headset to experience three-dimensional data is insufficient or even counterproductive. We have diverging empirical studies that have shown the advantages and disadvantages of immersive experiences [16, 34, 39, 46]. Like any other communication medium in education, research, and decision-making, we need basic research that carefully examines the technology itself and its design choices. Comparable to the developing science around visualization, we need a science around

immersive experiences that deconstructs its technology and design choices to establish evidence-based recommendations for improving immersive experiences.

On the technology side, we find questions that mainly address scalability issues. While immersive technology in general is becoming tremendously more accessible, it is still the case that not everyone will be accessing a high-end gaming computer; and this might not be a problem. Together with my team, we have conceptualized this aspect as SENSATIUM, the sensing-scalability continuum that captures the fact that an increase in sensing comes at a cost [29, 31]. An increase in sensing allows for higher levels of interaction fidelity and ultimately a more natural user experience. In conjunction with other aspects of fidelity, such as the display, it is essential to address the system characteristics' effects on both subjective and objective performance measures.

Equally important are design choices made in immersive experiences. Design choices change the flow of an experience [27]; they affect the sense of presence either in the environment [67] or with other agents [50]. Is it, for example, sufficient to capture physical environments and replicate them in immersive experiences, or do we gain more desirable outcomes by gamifying the experience? Do immersive experiences indeed paradigmatically change how we communicate, educate, and make decisions about spatial environments? How do we establish a science of immersive experiences that guides both design and technological choices? How do we address critical questions tailored to the needs of geospatial sciences?

The appeal of immersive experiences, especially for geospatial sciences, has undoubtedly increased in light of COVID-19. With restrictions in place on social interaction, travel, and education, we need communication media that go beyond teleconferencing and provide means to maintain core aspects of human communication. Even disciplines such as the geosciences, which elevate the field to a defining concept of the discipline, are witnessing an opening of minds towards remote learning opportunities [17, 30].

Immersive technologies will find their central place in the geospatial sciences because of their substantial appeal for communicating spatial data and information. While they have been discussed in several academic communities for decades, recent advancements will allow for widespread accessibility and a community large enough to empirically address central questions of how to design efficient and effective immersive experiences.

Acknowledgments

References

[1] BAILENSON, J. *Experience on demand: What virtual reality is, how it works, and what it can do.* W. W. Norton & Company, New York, NY, 2018.

[2] BARSALOU, L. W. Perceptual symbol systems. *Behavioral and Brain Sciences 22*, 4 (1999), 577–609.

[3] BIOCCA, F., HARMS, C., AND BURGOON, J. K. Toward a more robust theory and measure of social presence: Review and suggested criteria. *Presence: Teleoperators and Virtual Environments 12*, 5 (2003), 456–480. doi:10.1162/105474603322761270.

[4] BLASCOVICH, J., AND BAILENSON, J. *Infinite reality: Avatars, eternal life, new worlds, and the dawn of the virtual revolution*, 1st ed. ed. William Morrow, New York, 2011.

[5] BLASCOVICH, J., LOOMIS, J., BEALL, A. C., SWINTH, K. R., HOYT, C. L., AND BAILENSON, J. N. Immersive virtual environment technology as a methodological tool for social psychology. *Psychological Inquiry 13*, 2 (2002), 103–124. doi:10.2307/1449167.

[6] BOWMAN, D. A., AND MCMAHAN, R. P. Virtual reality: How much immersion is enough? *Computer 40*, 7 (2007), 36–43.

[7] CARRIVICK, J. L., SMITH, M. W., AND QUINCEY, D. J. *Structure from Motion in the Geosciences*. John Wiley & Sons, Ltd, Chichester, UK, 2016. doi:10.1002/9781118895818.

[8] CHANDLER, T., CORDEIL, M., CZAUDERNA, T., DWYER, T., GLOWACKI, J., GONCU, C., KLAPPERSTUECK, M., KLEIN, K., MARRIOTT, K., SCHREIBER, F., AND WILSON, E. Immersive analytics. In *2015 Big Data Visual Analytics (BDVA)* (2015), pp. 1–8. doi:10.1109/BDVA.2015.7314296.

[9] CHANDLER, T., CORDEIL, M., CZAUDERNA, T., DWYER, T., GLOWACKI, J., GONCU, C., KLAPPERSTUECK, M., KLEIN, K., MARRIOTT, K., SCHREIBER, F., AND WILSON, E. Immersive analytics. In *2015 Big Data Visual Analytics (BDVA)* (2015), pp. 1–8. doi:10.1109/BDVA.2015.7314296.

[10] CHEAH, C. S. L., BARMAN, S., VU, K. T. T., JUNG, S. E., MANDALAPU, V., MASTERSON, T. D., ZUBER, R. J., BOOT, L., AND GONG, J. Validation of a virtual reality buffet environment to assess food selection processes among emerging adults. *Appetite 153* (2020), 104741. doi:10.1016/j.appet.2020.104741.

[11] CHEN, M., AND LIN, H. Virtual geographic environments (VGEs): originating from or beyond virtual reality (VR)? *International Journal of Digital Earth 11*, 4 (2018), 329–333. doi:10.1080/17538947.2017.1419452.

[12] CHIRICO, A., FERRISE, F., CORDELLA, L., AND GAGGIOLI, A. Designing awe in virtual reality: An experimental study. *Frontiers in psychology 8* (2017), 2351. doi:10.3389/fpsyg.2017.02351.

[13] CRESSWELL, T. *Place: An introduction*, second edition ed. Wiley Blackwell, Chichester, West Sussex, 2015.

[14] CSIKSZENTMIHALYI, M. *Flow: The psychology of optimal experience : <steps toward enhancing the quality of life>*. Harper Collins Publishers, New York, NY, 1991.

[15] CUNNINGHAM, T. D., AND LANSIQUOT, R. D. Modeling interdisciplinary place-based learning in virtual worlds: Lessons learned and suggestions for the future. In *Interdisciplinary Perspectives on Virtual Place-Based Learning*, R. D. Lansiquot and S. P. MacDonald, Eds. Springer International Publishing, Cham, 2019, pp. 133–145. doi:10.1007/978-3-319-66014-1_7.

[16] DEDE, C. Immersive interfaces for engagement and learning. *Science 323*, 5910 (2009), 66–69. doi:10.1126/science.1167311.

[17] DOLPHIN, G., DUTCHAK, A., KARCHEWSKI, B., AND COOPER, J. Virtual field experiences in introductory geology: Addressing a capacity problem, but finding a pedagogical one. *Journal of Geoscience Education 67*, 2 (2019), 114–130. doi:10.1080/10899995.2018.1547034.

[18] DWYER, T., MARRIOTT, K., ISENBERG, T., KLEIN, K., RICHE, N., SCHREIBER, F., STUERZLINGER, W., AND THOMAS, B. H. Immersive analytics: An introduction. In *Immersive analytics*, K. Marriott, F. Schreiber, T. Dwyer, K. Klein, N. Riche, T. Itoh, W. Stuerzlinger, and B. H. Thomas, Eds., vol. 11190. Springer, Cham, Switzerland, 2018, pp. 1–23. doi:10.1007/978-3-030-01388-2_1.

[19] GIBSON, J. *The ecological approach to visual perception*. Houghton Mifflin, Boston, MA, 1979.

[20] HAGGIS-BURRIDGE, M. Four better ways to talk about 'immersion', 2020.

[21] HEDLEY, N. R., BILLINGHURST, M., POSTNER, L., MAY, R., AND KATO, H. Explorations in the use of augmented reality for geographic visualization. *Presence 11*, 2 (2002), 119–133. doi:10.1162/1054746021470577.

[22] HELBIG, C., BAUER, H.-S., RINK, K., WULFMEYER, V., FRANK, M., AND KOLDITZ, O. Concept and workflow for 3D visualization of atmospheric data in a virtual reality environment for analytical approaches. *Environmental Earth Sciences 72*, 10 (2014), 3767–3780. doi:10.1007/s12665-014-3136-6.

[23] HUANG, J., LUCASH, M. S., SCHELLER, R. M., AND KLIPPEL, A. Walking through the forests of the future: using data-driven virtual reality to visualize forests under climate change. *International Journal of Geographical Information Science* (2020), 1–24. doi:10.1080/13658816.2020.1830997.

[24] IJSSELSTEIJN, W. A. Presence in the past: What can we learn from media history? In *Being there*, W. A. IJsselsteijn, G. Riva, and F. Davide, Eds., Emerging communication. Studies in new technologies and practices in communication. IOS, Amsterdam and Oxford, 2003, pp. 17–40.

[25] JERALD, J. *The VR Book: Human-centered design for virtual reality*, first edition ed., vol. 8 of *ACM Books*. Association for Computing Machinery and Morgan & Claypool Publishers, New York, NY and San Rafael, 2016. doi:10.1145/2792790.

[26] JONES, J. A., SWAN, J. E., SINGH, G., KOLSTAD, E., AND ELLIS, S. R. The effects of virtual reality, augmented reality, and motion parallax on egocentric depth perception. In *Proceedings of the 5th Symposium on Applied Perception in Graphics and Visualization*

(New York, NY, USA, 2008), APGV '08, Association for Computing Machinery, pp. 9–14. doi:10.1145/1394281.1394283.

[27] KIILI, K. Digital game-based learning: Towards an experiential gaming model. *The Internet and Higher Education 8*, 1 (2005), 13–24. doi:10.1016/j.iheduc.2004.12.001.

[28] KLIPPEL, A., ZHAO, J., JACKSON, K. L., LAFEMINA, P., STUBBS, C., OPREAN, D., WALLGRÜN, J. O., AND BLAIR, J. Transforming earth science education through immersive experiences – delivering on a long held promise. *Journal of Educational Computing Research 57*, 7 (2019), 1745–1771. doi:10.1177/0735633119854025.

[29] KLIPPEL, A., ZHAO, J., OPREAN, D., WALLGRÜN, J. O., CHANG, J. S.-K., WALL-GRUN, J. O., AND CHANG, J. S.-K. Research framework for immersive virtual field trips. In *IEEE Conference on Virtual Reality and 3D User Interfaces. KELVAR: The Fourth IEEE VR Workshop on K-12+ Embodied Learning through Virtual and Augmented Reality.* IEEE, 2019, pp. 1612–1617. doi:10.1109/VR.2019.8798153.

[30] KLIPPEL, A., ZHAO, J., OPREAN, D., WALLGRÜN, J. O., STUBBS, C., LA FEMINA, P., AND JACKSON, K. L. The value of being there: toward a science of immersive virtual field trips. *Virtual Reality 1*, 4 (2019), 24. doi:10.1007/s10055-019-00418-5.

[31] KLIPPEL, A., ZHAO, J., SAJJADI, P., WALLGRÜN, J. O., BAGHER, M. M., AND OPREAN, D. Immersive place-based learning – an extended research framework. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW).* IEEE, Piscataway, NJ, 2020, pp. 449–454. doi:10.1109/VRW50115.2020.00092.

[32] KUHN, W. Geospatial semantics: Why, of what, and how? In *Journal on Data Semantics III* (Berlin, Heidelberg, 2005), S. Spaccapietra and E. Zimányi, Eds., Springer Berlin Heidelberg, pp. 1–24.

[33] LAGES, W. S., AND BOWMAN, D. A. Move the object or move myself? walking vs. manipulation for the examination of 3D scientific data. *Frontiers in ICT 5* (2018), 236. doi:10.3389/fict.2018.00015.

[34] LEGAULT, J., ZHAO, J., CHI, Y.-A., CHEN, W., KLIPPEL, A., AND LI, P. Second language learning and embodied experience via virtual reality. *Languages 4*, 1 (2019). doi:10.3390/languages4010013.

[35] LI, P., LEGAULT, J., KLIPPEL, A., AND ZHAO, J. Virtual reality for student learning: Understanding individual differences. *Human Behaviour and Brain 1*, 1 (2020), 28–36. doi:10.37716/HBAB.2020010105.

[36] LIN, H., AND BATTY, M., Eds. *Virtual geographic environments.* ESRI Press, Redlands, Calif., 2012.

[37] LIN, H., CHEN, M., LU, G., ZHU, Q., GONG, J., YOU, X., WEN, Y., XU, B., AND HU, M. Virtual geographic environments (VGEs): A new generation of geographic analysis tool. *Earth-Science Reviews 126* (2013), 74–84. doi:10.1016/j.earscirev.2013.08.001cirev.2013.08.001.

[38] LIU, J.-G., AND MASON, P. J. *Image processing and GIS for remote sensing: Techniques and applications / Jian Guo Liu and Philippa J. Mason, Department of Earth Science and Engineering, Imperial College London*, second edition ed. Wiley Blackwell, Chichester, West Sussex, 2016.

[39] MAKRANSKY, G., TERKILDSEN, T. S., AND MAYER, R. E. Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction* (2017). doi:10.1016/j.learninstruc.2017.12.007.

[40] MARKOWITZ, D. M., LAHA, R., PERONE, B. P., PEA, R. D., AND BAILENSON, J. N. Immersive virtual reality field trips facilitate learning about climate change. *Frontiers in psychology 9* (2018), 2364. doi:10.3389/fpsyg.2018.02364.

[41] MICHAEL, D. R., AND CHEN, S. L. *Serious Games: Games That Educate, Train, and Inform*. Muska & Lipman/Premier-Trade, 2005.

[42] MILGRAM, P., AND KISHINO, F. A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems E77-D*, 12 (1994), 1321–1329.

[43] MULLER, P. Procedural modeling of cities. In *ACM SIGGRAPH 2006 Courses* (New York, NY, USA, 2006), SIGGRAPH '06, Association for Computing Machinery, pp. 139–184. doi:10.1145/1185657.1185716.

[44] OHTA, Y., AND TAMURA, H. *Mixed Reality: Merging Real and Virtual Worlds*, 1 ed. Springer Publishing Company, Incorporated, 2014.

[45] OLIVER, K. J., AND BURNETT, G. E. Learning-oriented vehicle navigation systems: a preliminary investigation in a driving simulator. In *Proceedings of the 10th international conference on Human computer interaction with mobile devices and services*. ACM, New York, NY, 2008, pp. 119–126.

[46] PARONG, J., AND MAYER, R. E. Learning science in immersive virtual reality. *Journal of Educational Psychology* (2018). doi:10.1037/edu0000241.

[47] PIAGET, J. *To understand is to invent: The future of education*, 1st viking compass ed. Viking Press, New York, N.Y., 1974.

[48] QIN, H., PATRICK RAU, P.-L., AND SALVENDY, G. Measuring player immersion in the computer game narrative. *International Journal of Human-Computer Interaction 25*, 2 (2009), 107–133. doi:10.1080/10447310802546732.

[49] SAJJADI, P., VLIEGHE, J., AND DE TROYER, O. Evidence-based mapping between the theory of multiple intelligences and game mechanics for the purpose of player-centered serious game design. In *2016 8th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES)* (2016), pp. 1–8. doi:10.1109/VS-GAMES.2016.7590348.

[50] SCHROEDER, R., Ed. *The Social Life of Avatars: Presence and Interaction in Shared Virtual Environments*. Springer, London, 2001.

[51] SCOBLE, R., AND ISRAEL, S. *The fourth transformation: How augmented reality and artificial intelligence change everything*, 1st edition ed. Patrick Brewster Press and CreateSpace, a DBA of On-Demand Publishing, LLC, [United States] and [Charleston, S.C.], 2017.

[52] SEMKEN, S., AND FREEMAN, C. B. Sense of place in the practice and assessment of place-based science teaching. *Science Education 92*, 6 (2008), 1042–1057. doi:10.1002/sce.20279.

[53] SEMKEN, S., WARD, E. G., MOOSAVI, S., AND CHINN, P. W. U. Place-based education in geoscience: Theory, research, practice, and assessment: Theory, research, practice, and assessment. *Journal of Geoscience Education 65*, 4 (2018), 542–562. doi:10.5408/17-276.1.

[54] SHEPPARD, STEPHEN R. J. Making climate change visible: A critical role for landscape professionals. *Landscape and Urban Planning 142* (2015), 95–105. doi:10.1016/j.landurbplan.2015.07.006.

[55] SHERNOFF, D. J., CSIKSZENTMIHALYI, M., SHNEIDER, B., AND SHERNOFF, E. S. Student engagement in high school classrooms from the perspective of flow theory. *School Psychology Quarterly 18*, 2 (2003), 158–176. doi:10.1521/scpq.18.2.158.21860.

[56] SIMPSON, M. *Scale and Space: Representations in Immersive Virtual Reality*. Ph.d., The Pennsylvania State University, University Park, PA USA, 2020.

[57] SIMPSON, M., WALLGRÜN, J. O., KLIPPEL, A., YANG, L., GARNER, G., KELLER, K., OPREAN, D., AND BANSAL, S. Immersive analytics for multi-objective dynamic integrated climate-economy (dice) models. In *Proceedings of the 2016 ACM Companion on Interactive Surfaces and Spaces - ISS Companion '16* (New York, New York, USA, 2016), M. Hancock, N. Marquardt, J. Schöning, and M. Tory, Eds., ACM Press, pp. 99–105. doi:10.1145/3009939.3009955.

[58] SLATER, M. Measuring presence: A response to the Witmer and Singer presence questionnaire. *Presence: Teleoperators and Virtual Environments 8*, 5 (1999), 560–565. doi:10.1162/105474699566477.

[59] SPENCE, A., POORTINGA, W., AND PIDGEON, N. The psychological distance of climate change. *Risk analysis : an official publication of the Society for Risk Analysis 32*, 6 (2012), 957–972. doi:10.1111/j.1539-6924.2011.01695.x.

[60] TROPE, Y., AND LIBERMAN, N. Construal-level theory of psychological distance. *Psychological Review 117*, 2 (2010), 440–463. doi:10.1037/a0018963.

[61] VYGOTSKY, L. S., AND COLE, M. *Mind in society: The development of higher psychological processes*. Harvard University Press, Cambridge, Mass. and London, 1978.

[62] WELLNER, P., MACKAY, W., AND GOLD, R. Back to the real world. *Communications of the ACM 36*, 7 (1993), 24–27. doi:10.1145/159544.159555.

[63] WILSON, M. Six views of embodied cognition. *Psychonomic Bulletin and Review 9*, 4 (2002), 625–636.

[64] WIRTH, W., HARTMANN, T., BÖCKING, S., VORDERER, P., KLIMMT, C., SCHRAMM, H., SAARI, T., LAARNI, J., RAVAJA, N., GOUVEIA, F. R., BIOCCA, F., SACAU, A., JÄNCKE, L., BAUMGARTNER, T., AND JÄNCKE, P. A process model of the formation of spatial presence experiences. *Media Psychology 9*, 3 (2007), 493–525. doi:10.1080/15213260701283079.

[65] WITMER, B. G., AND SINGER, M. J. Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments 7*, 3 (1998), 225–240. doi:10.1162/105474698565686.

[66] YANG, Y., JENNY, B., DWYER, T., MARRIOTT, K., CHEN, H., AND CORDEIL, M. Maps and globes in virtual reality. *Computer Graphics Forum 37*, 3 (2018), 427–438. doi:10.1111/cgf.13431.

[67] ZHAO, J., AND KLIPPEL, A. Scale - unexplored opportunities for immersive technologies in place-based learning. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Osaka, Japan*. IEEE, 2019, pp. 155–162. doi:10.1109/VR.2019.8797867.

[68] ZHAO, J., SENSIBAUGH, T., BODENHEIMER, B., MCNAMARA, T. P., NAZARETH, A., NEWCOMBE, N., MINEAR, M., AND KLIPPEL, A. Desktop versus immersive virtual environments: effects on spatial learning. *Spatial Cognition & Computation: An Interdisciplinary Journal* (2020), 1–36. doi:10.1080/13875868.2020.1817925.