Immersive Learning Environments at Scale: Constraints and Opportunities

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The expansion of online education into massive open online courses (MOOCs) and equipment have created a unique opportunity for delivering immersive learning experiences at scale. However, although the inclusivity of the MOOC ecosystem can be commended, many online courses lack key benefits associated with traditional classroom environments: immersive, engaging, and team-driven learning opportunities. Immersive learning environments (ILEs) address these educational gaps but has not been able to operate at the broad scale that MOOCs offer. Importantly, ILEs address opportunities missing from MOOC systems, they add unique learning opportunities that would also be missing in a traditional classroom. The inclusion of this virtual reality technology is pivotal topic for educational research. This theoretical paper will briefly define immersive learning environments and the potential benefits of incorporating immersive learning environments into scalable educational systems. We will also consider developers constraints on creating these online ecosystem and suggested strategies for overcoming them.

INTRODUCTION

The broad concept of virtual reality encompasses many different interfaces, equipment, and experiences (Hepperle, Weiß, Siess, & Wölfel, 2019). From large, fully immersive virtual worlds (Davis, Proctor, & Shageer, 2016), to using a digital overlay with the real world around the user (Siegle, 2019), the use of virtual reality has evolved leaps and bounds in recent years. This review focuses on a subset of virtual reality—*immersive learning environments* (ILEs)—defined as fully and visually immersive environments in which a 2D image surrounds the user to create or enhance a 3D space.

Prior research has demonstrated that ILEs offer broad applicability across learning domains (e.g., math, chemistry, combat training, and safety) along with evidence of learning benefits. One critical question, however, is how to implement and attain such outcomes at scale. How can developers and educators transition these tools from isolated studies and interventions to broader and larger audiences? Although the topic of using affordable ILEs for teaching has been discussed, often left out are the constraints on the development side of the ILE software, and how to develop software within these limits (Rodriguez, 2016). This review briefly defines ILEs and evidence of their utility, and then considers both barriers for scaling up ILEs and evidence-based strategies developers can utilize for overcoming these barriers. We articulate recommendations and design principles for such scale up.

IMMERSIVE LEARNING ENVIRONMENTS

A feeling of immersion can be achieved through the use of virtual reality (VR) head-mounted displays (HMDs), room-like Cave Automatic Virtual Environments (CAVEs) (Nelson & Ketelhut, 2007), or by placing a digital overlay of graphics and sound over a real-world setting as augmented reality (AR) (Siegle, 2019). In mixed reality (MR), virtual interactions are integrated with non-virtual, physical components (Frank & Kapila, 2017). Importantly, computer simulations in which a virtual space is viewed only on a 2D display (i.e., does not surround the user) are not considered a fully immersive environment (Korteling, Helsdingen, & Sluimer, 2017). Although simulations are valuable learning tools (Cant & Cooper, 2017), the immersion and depth provided by ILEs can uniquely build upon these benefits (Arango-López, Cerón Valdivieso, Collazos, Gutiérrez Vela, & Moreira, 2019).

Applications and Benefits of ILEs

ILEs have been studied and applied in a vast array of educational and training domains. Diverse usage in K-12 and higher education settings (see Cook et al., 2019; Zheng, Xing, & Zhu, 2019), such as mobile AR instructional materials for mathematics (Chen, 2019), or VR for chemistry simulations (O'Malley, Agger, & Anderson, 2015). Several applied fields have also implemented ILEs to aid in the teaching or training of specific skill sets. For example, the U.S. Marine Corps has explored VR to train soldiers for combat scenarios (Strachan, 2016). Similarly, VR simulators have been used in medical training for both emergency response and surgery (Khan et al., 2019) and for teaching long-term patient care practices to nursing staff (Gdanetz et al., 2018). VR has also been used to train mining equipment operators (Neustupa, Danel, & Řepka, 2011) and to provide safety training in construction sites (Norris, Spicer, & Byrd, 2019).

The equipment used to interact with these ILEs varies from organization to organization, depending on user needs (e.g., ways to interact with the tools) and budget (Ritz & Buss, 2016). The most common equipment used for ILEs are mobile phone technologies that offer AR overlays (Siegle, 2019) and HMDs that use headsets or lightweight glasses (Yu, Zhou, Wang, & Zhao, 2019). However, more elaborate technology also has been developed. CAVE systems are enclosed spaces in which the walls, floor, and celling have a virtual world projected onto them from the outside, allowing for users to experience a full range of movement and vision (Ritz & Buss, 2016). Walking through a virtual world has also made possible via the use of motion platforms similar to treadmills; the newest omnidirectional platforms offer 360 degrees of freedom for user movement (Monroy, Lutz, Chalasani, & Smolic, 2018).

Immersion is fundamental to the design and implementation of ILEs. The feeling of being present in the virtual space is hypothesized to enrich the learning experience (Gardner & Elliott, 2014), both cognitively (Georgiou & Kyza, 2018), and motivationally (Chen, 2019). In support of these claims, studies have indeed observed increase motivation for learners leading to learning gains (Arango-López et al., 2019). Gains in motivation due to working in ILEs has also been found for those with learning anxieties, with high anxiety learners reporting lower levels of anxiety and higher confidence and satisfaction when using mobile AR learning systems (e.g., math anxiety, Chen, 2019). Remote laboratories can also enable students to use (virtual) equipment that would have been inaccessible, such as working on analog electronics, thus exciting students with new opportunities to learn (Garcia-Zubia et al., 2017). Studies have evaluated the impact of ILEs within K-12 and higher education (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014), and ILEs have generally been shown to have a positive impact on conceptual learning, critical thinking, systems thinking, and knowledge organization (Georgiou & Kyza, 2018).

Using ILEs, students can travel to virtually recreated locations such as national monuments, geographical wonders, and museums (Gaylord-Opalewski & O'Leary, 2019). The nature of ILEs allows learners experience a sense of being at the location even when physical travel is not possible (Gardner & Elliott, 2014). Similarly, ILEs are able to simulate locations that would normally be too hazardous or expensive to replicate; ILEs allow exploration of these locations with no actual danger to participants (Fuentes, 2018).

Finally, one relatively recent innovation is the ability to connect ILEs to an online network, thus creating opportunities for distance learning. Learners around the world can work together in a shared virtual environment (Umoren et al., 2107). For example, networked team training ILEs can enable otherwise isolated learners to acquire and hone skills that can only be practiced with others, thus improving team performance (Eppich et al., 2015), leadership (Rosenman, Vrablik, Brolliar, Chipman, & Fernandez, 2019), and communication (Zemliansky, 2012).

MOOCs, Simulations, and ILEs

Other recent innovations in online education have sought to deliver instructional opportunities to regions and populations who cannot readily access traditional courses (Power, & Coulson, 2015), and to do so *at scale*—empowering large numbers of learners regardless of distance (e.g., Freericks, Cutler, Kruse, & Vieira, 2019; O'Malley et al., 2015). These massively open online courses (MOOCs) can include computer simulations, which allow learners to visually explore and interact with various processes and phenomena (e.g., Song et al., 2019).

As noted above, however, computer simulations lack several of the affordances of virtual worlds and ILEs. Specifically, there are three critical contrasts between computer-based simulations and ILEs. First, ILEs potentially offer a much higher level of interactive immersion, which has been associated with improved learning outcomes (e.g., Arango-López et al., 2019). Second, ILEs typically offer a larger virtual environment and opportunities to explore than computer-based simulations (Kim, Park, & Baek, 2009). Computer simulations tend to be more tightly scripted, only advancing once the user performs a specific action. In contrast, ILEs are often open-ended, allowing for users to learn via both formal and informal approaches (Freitas & Neumann, 2009). Finally, computer-based simulations are less able to offer the freedom of embodied movement available in ILEs (Gautam, Williams, Terry, Robinson, & Newbill, 2018; Monroy et al., 2018; Ritz & Buss, 2016). ILEs with HMDs, glasses, or other motion detection allow learners to physically explore and move around in the virtual space.

One question that emerges is how ILEs could be delivered at scale in MOOCs or MOOC-like settings. If ILEs afford unique learning opportunities and processes that are not replicated by simulations, a worthwhile goal is to explore the potential constraints or strategies for doing so. We consider these questions in the remainder of the paper.

ILEs AT SCALE: CONSTRAINTS AND RECOMMENDATIONS

Although scaling up ILEs is increasingly plausible, not all aspects of scale up are practical. There are (at least) three key constraints for implementing ILEs at scale: *affordability*, *technical points of entry*, and *user knowledge*. This section will discuss each constraint that developers of ILE software will face, suggests ways to overcome the obstacles, and consider formats that may be impossible given these limits.

Affordability

A traditional college education is expensive, and costs continue to rise, which poses a challenge to the over 366 million youth who are currently not enrolled. Ma and Lee (2019) have found that to maintain the MOOC-inspired mission of realizing the untapped potential of unenrolled individuals, the courses must remain affordable. In a study surveying over eight hundred individuals, the accessibility and cost of the MOOCs was the second most valued aspect of the courses. This aspect came in second only behind the perceived usefulness of the courses (Ma & Lee, 2019). The use of virtual reality equipment and the creation of ILEs have been praised in applied fields for reducing training costs (Fung et al., 2015). However, this praise emerges from a perspective of reducing high costs rather than maintaining low costs. For example, in the field of medicine, a VR headset costing less than $1,500 USD is considered low cost (Bing et al., 2019). Virtual reality equipment can be expensive, and these costs are a non-negligible constraint for deploying ILEs in MOOCs for the general population.

One recommendation is for developers to *focus on the tools already available* to many users: smartphones and tablets. Using such mobile devices, AR has already reached hundreds of millions of users through free or low-cost applications available for download (Kim, Kim, & Song, 2019). Some applications can be used as-is for AR experiences (i.e., overlaying the real world), or can be combined with low-cost, light-weight HMDs in which a smartphone is placed inside a second device to provide the user with a VR headset experience

(Qiu, Qin, Gao, & Shen, 2019). These HMDs that are available for purchase for less than eight US dollars and have been found to be a suitable way of incorporating the ILEs for a low-income population (Vishwanath, Kam, & Kumar, 2017). Applied research has further tested these low-cost HMDs and have found that using mobile technology from 2013 (Samsung Galaxy Note 3) was practical for creating a realistic VR simulation for engineering and construction design (Hilfert & König, 2016). Leveraging extant mobile technologies and familiar tools already used by learners will be critical for scaling up ILEs (Thomson, 2018).

Technical Points of Entry

The cost constraint intersects and conflicts with constraints of technological sophistication. Technologies for delivering ILEs might be physically robust and able to operate the required software and controls (Thomson, 2018). Fortunately, evidence suggests that many mobile technologies are feasible for basic AR and VR purposes (e.g., Qiu et al., 2019). There is no current universal standard for tablet or smartphone design, resulting in a range of features, interfaces, operating systems, and networks.

Thus, the developers must *design the ILEs software for mid-to-low range variations of these devices*; designing for the lowest range of functionality maximizes inclusion (Encalada & Castillo Sequera, 2017). Similarly, ILE software must be designed for compatibility across operating systems (Thomson, 2018). Designing within a single system (e.g., iOS or Android, but not both) unfairly and significantly restricts the population of potential users. These technical constraints can result in less visually impressive ILEs but managing technical requirements to maximize accessibility is essential for scale up and for leveraging the resources that learners have at their disposal (Encalada & Castillo Sequera, 2017).

User Knowledge

Chen and colleges (2019) have found that adhering to strong user-centered design practices is crucial for successful MOOC programs. In addition to users' financial and technological resources, we must also consider their range of technical background knowledge and experience. Given a target demographic of thousands, millions, or hundreds of millions of learners, it is unreasonable to expect high or moderate technical prowess. ILE design must consider learners' abilities just as with any product (Chen, Gao, Yuan, & Tang, 2019).

An obvious but powerful constraint is the likelihood that learners will be unfamiliar with VR or AR interfaces. Thus, in addition to learning new conceptual content, ILEs represent a novel technology that must also be mastered (Verdi & Kulhavy, 2002). As above, using familiar devices somewhat mitigates this learning curve, but the novelty or unfamiliarity of AR/VR experiences remains. ILE software and devices must be developed with users that have no technical experience in mind.

Developers should *provide meaningful tutorials and online support* for navigating the new experiences of AR or VR. Jacobs and colleges (2016) have shown that if done well, virtual instruction tutorials can promote learning and engagement in virtually based lessons. Years of research have produced a short list of recommendations; that users learn best from of short and relevant tutorials, that are audibly and visibly salient, and use familiar and relaxed narration. Additionally, the tutorials should be created in a format that supports user analytics, with yearly evaluations of what revisions can be made to improve the next version of the tutorials (Jacobs, Dalal, & Dawson, 2016).

Impractical or Impossible?

The above constraints (affordability, technical resources, and knowledge) are not insurmountable in many cases, but there are approaches that significantly violate these limits. Specifically, advanced virtual spaces using CAVE technology or motion platforms—although useful and effective in promoting learning in immersive environments—seem impossible to scale at this time (e.g., Ritz & Buss, 2016). Notably, much of the research regarding ILEs has been conducted using these higher end technologies (Gdanetz et al., 2018). Although several studies have explored ILEs on mobile devices (e.g., Frank & Kapila, 2017), this research gap calls for further work on scalable and low-end version of ILEs. One question is whether the diminished quality of these versions might reduce the previously observed benefits for learning (e.g., Bing et al., 2019).

Developers must *avoid technology that is implausible to scale* in ILEs. CAVE and motion technology are not widely accessible, instead developers must focus must be on feasible options such as AR technology. Successful implementation of AR has been demonstrated when using the technology to elaborate existing lessons, such as displaying pictures, graphs, and video clips to enhance the course and increase motivation and participation (Chen, 2019). Emulating this success of building off an existing lesson plan, rather than building from the ground up with VR in mind, is likely the first place to start this approach (Thomson, 2018).

DISCUSSION

The process of implementing ILE into the scale of a MOOC system is not without its challenges. As discussed in this paper, many of these challenges will fall onto the shoulders of the software developers. Recommended considerations include

- Focus development on devices already owned by the majority of the user base, smartphones and tablets
- Design the ILE software to run on mid-to low variations of smartphones and tablets
- Accompany the creation of ILE software with meaningful and continuously evaluated tutorials
- Avoid technology that is impractical to scale up, CAVEs and motion platforms

Additionally, after developers are able to accomplish all of this, there would be testing needed to ensure that the ILEs created have not changed or diminished too greatly from those in research that have shown such promising learning benefits.

Future Research

As the current unknown is whether or not such a scaled back form of ILEs would work in the scaled-up MOOC setting, research should first be conducted with these low-end mobile options. The replication of studies that used state of the art materials and equipment must be done with the more scalable mobile options discussed in this paper, testing variables such as: the level of immersion (Arango-López et al., 2019), reduction in anxiety for learning (Chen, 2019), personal growth in conceptual learning abilities (Georgiou & Kyza, 2018), and improved team dynamics (Eppich et al., 2015). Without knowing that these benefits would still be possible utilizing less powerful means of producing ILEs for learning, the entire operation of moving ILEs to scale could be fruitless. If it is found that ILEs done on this level of scale still hold the same benefits, then there should be haste given to starting research into the development of the software expressed above, that would allow integration of such a ILE into the MOOCs system.

However, if such findings are not observed—if the benefits do not translate when replicated by such lower, scaled-up means—this does not equivalate to saying that ILEs have no place in the future of MOOC systems. Instead this merely means that it could not be practical given the current state of technology. Should this unfortunately be the case, it remains imperative that those involved with the study of education and MOOCs instead find where this line is in the technological sand, of what is required to create a worthy ILE, and when the mass public's equipment catches up with this required level, the iron will be hot to strike for the creation of these scaled ILEs.

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