COMPARING XR AND DIGITAL FLIPPED METHODS TO MEET LEARNING OBJECTIVES

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ABSTRACT

Digital learning has become increasingly important over the last decade as students and educators adopt new types of technology to keep up with emerging trends. The advent of the Covid-19 pandemic accelerated this rate of change in the higher education sector, leading to remote laboratory experiences and video conferencing becoming increasingly normal. In the wake of this transition, the priority is to understand how these technologies can be blended into existing teaching methodologies, in a complementary way, that enhances the student's pedagogical experience.

The upcoming pilot study will compare three digital-based learning simulations to see which has the most beneficial effect on practical student laboratory experiences. Engineering students will be allocated a grouping that are exposed to one of three forms of digital "pre-lab" laboratory simulation and their academic performance is assessed following the physical laboratory. The three forms are a 2D photography "iLabs" simulation, a web-based "low fidelity" simulator and a Unity immersive Virtual Reality (iVR) lab simulator. All three simulation methods will be based on the same empirically derived data, that was taken from the same laboratory equipment that the students will use in the final part of the study. As a control, another group of students will not receive a pre-lab simulation, but a pre-lab quiz.

This study will build upon existing work carried out in the field of virtual labs, that indicates these experiences can help reinforce student learning outcomes, whilst also unpicking the complex relationship between simulation immersion, fidelity and memory recall in a learning context. In addition, the study will give an opportunity to perform a detailed cost versus pedagogical impact assessment, as each of these simulations has been designed and built from the ground up by the authors.

KEYWORDS

Extended Reality, Immersive Technology, Distance Education, Online Learning,
Human-computer interface (CDIO Standards 6,7,8,10).

INTRODUCTION

Extended Reality or XR is a label commonly used to categorize many different types of immersive technologies and concepts. Within this field, there is a range of different specialist areas of study, including; Virtual Reality (VR), a technology that creates interactive virtual environments, Augmented Reality (AR), a technology that superimposes virtual information as an overlay on the physical world and Mixed Reality (MR), that combines elements of the previous two within a single display (Suh & Prophet, 2018).

The field of Extended Reality (XR) has had a resurgence of interest in the last couple of decades due to technological progress and investment in the associated hardware and software. Alongside commercial and domestic interest, there has also been an explosion of interest in XR within Higher Education (HE) research communities. A recent study of 423 teachers in HE on the didactic use of VR in the classroom recommended that universities as a matter of priority should implement training plans in digital learning for their most experienced staff (Vergara et al., 2021). In the HE sector, the largest uptake of this technology for research has been in the subject of engineering, with 24% of all papers devoted to it. This research has been applied to many disciplines within the field, including manufacturing training (Muller et al., 2017), workshop health and safety (Carruth, 2017), fluid mechanics (Cruz & Mendoza, 2018), electrical theory (AlAwadhi et al., 2017) and chemical/biological simulation (Kumar et al., 2021).

Educational Approaches

One reason XR has been vigorously pursued in HE is the many perceived benefits it purports to give to the learning experience, such as “giving users the freedom to explore knowledge and environments through means not usually afforded to them by traditional methods" (Logeswaran et al., 2021). However, the assessment of merit in this regard has been slightly undermined to date due to the lack of studies created with a solid pedagogical framework. In their comprehensive literature review, Radianti et al. (2020) found that surprisingly as few as 32% of studies were associated with a sound pedagogical basis. Instead, most studies considered the technical possibilities first and applied teaching methods retrospectively.

Building on these findings, an increasing number of publications have started to incorporate pedagogical approaches from their inception in a more holistic manner. Most of this work focuses on two main types of pedagogical approach, didactic (i.e. the traditional teacher-centric format given in lecturing) and the “flipped” learner-centric method within a Constructivist framework (Logeswaran et al., 2021, Jong et al., 2020).

One branch of the latter, Connectivism, has also been suggested for incorporation into XR-based learning due to its aptitude as a collaborative working platform and ability to connect many different types of digital media in a Massive Open Online Course (MOOC) like format (Goldie, 2016, Zhang et al., 2018). In their recent user-centered interdisciplinary design study Fromm et al. (2021), looked at how the experiential learning modes (such as concrete experience, reflective observation, abstract conceptualization, and active experimentation) first defined by Kolb (1984) and further refined by Lewis & Williams (1994) can be designed into a VR experience.

Technical Hurdles

Alongside the pedagogical issues there are still a series of technical challenges that need to be addressed if the long-term adoption of XR is to become successful in HE. These include the gap in staff developmental skills and the lack of standardization in 3D software/asset workflow (Kumar et al. 2021, Soliman et al. 2021). Even though the price of XR hardware is constantly decreasing with increased domestic demand, hardware is still expensive compared with 2D experiences. XR hardware and software will require long-term maintenance, the scale of this is unknown. Reactions to the hardware itself, such as the Head Mounted Display (HMD) by participants can be highly variable. Some users experience physical issues such as “cybersickness” or nausea, eye strain and physical discomfort. However, it is thought that many of these problems will be addressed in the coming years as technology matures further.

XR, E-learning and Practical Teaching

Practical teaching in the laboratory is one aspect of undergraduate-level education that is central to a student's learning process. The benefits of doing these activities allow the development of both problem and project-based skills that are highly valuable to their future careers (Kyaw et al., 2019). With the advent of the Covid-19 pandemic, many experiences in the HE sector had to pivot away from face-to-face experiences and incorporate a digital provision that allowed teaching to proceed even in the event of total closure of a teaching campus. At the University of Sheffield, this took the form of remote access to experimental apparatus, interactive media embedded into Virtual Learning Environments (VLEs), MOOCs and video-based tutorials & lectures (Bangert et al., 2022). One aspect that was missing from many institutions during this period was the inclusion of immersive XR experiences in this digital content. Crucially, there appears to be an appetite from learners for a shift to incorporate this new paradigm, as Fromm et al. (2021) showed that “students demand a shift from traditional lectures to learning spaces that foster experiential learning”. The inclusion of this new approach could have also added benefits in the longer term, helping institutions deal with increasing levels of student recruitment, whilst maximizing situations of limited lab space and resources (Cobb et al., 2009).

The literature review paper by Soliman et al. (2021) highlights that there is evidence in multiple publications that the VR implementation of labs can make learning experiences more effective than traditional means. The authors also suggest that XR can be effectively used alongside e-learning/blended learning tools (such as Blackboard and Moodle) to engage with students and have beneficial pedagogical and cognitive effects. From a logistical perspective, XR (or E-Learning systems) can also be beneficial to institutions as it helps to decouple the timetabling restrictions of physical labs bookings and allows students to work at a speed they are most comfortable learning at (Schofield, 2012). In addition, accessibility and inclusivity are increased as it can facilitate distance learning, accommodate students/staff with varying disabilities (Logeswaran et al., 2021) and has the advantage of being readily multi-lingual) (Patle et al., 2019).

2D, 3D & Immersion

It is worth noting what constitutes VR. Following the description in Suh & Prophet (2018), VR can be broken into two subgroups: Non-immersive VR (nVR) - Typically displayed as an image on a computer screen or table/phone device, interaction normally comes from a keyboard/mouse, controller pads and touch screen control. Immersive VR (iVR) - These systems require users to wear HMDs and are linked to an immersive 3D VR environment.

A recent examination of iVR's potential for engineering design concluded that it can aid in context-dependent and independent constructivist learning possibly due to the stereoscopic view of objects in an iVR environment, something an nVR experience cannot provide (Horvat et al., 2022). However, it is worth noting this finding is not compared to that of a true 2D diagrammatic benchmark and Berthoud & Walsh (2020) also showed his nVR program proved effective at demonstrating 3D complex systems, such as fluid dynamics compared to traditional 2D diagrams/models and this increased their students subject understanding.

Both types of VR approaches can allow observation and interaction that is not feasible in real life, for example, the removal of safety guarding or demonstrating physical effects not typically visible to the naked eye (Kumar et al., 2021). It is arguable though, based on Dede's (2009) postulation, that iVR could lead to greater improvements in lateral thinking and knowledge as this technology "enables them to view a problem either from within the situation (egocentric) or from the outside (exocentric)."

The work by Kisker et al. (2021) also suggests that iVR could possibly have a greater impact (compared to nVR) due to the experience imprinting on the users' autobiographical memory due to the increased levels of immersion and facilitating better levels of recall because of it. The sense of immersion is considered to be the biggest advantage that iVR experiences have compared to transitional teaching methods like 2D videos (Makransky et al., 2020). In industry, studies relating to operator training simulators (OTS) have highlighted that 2D experiences fail to create a sense of realism for their users, versus that of their VR counterparts (Patle et al., 2019), however, the academic connotations of this have not been fully explored. Unfortunately, many of these user-centric factors are difficult to replicate consistently and prove experimentally, with many studies producing opposing findings. For example, some authors have linked high-level immersion to better learning outcomes, while others have also shown a negative impact on knowledge acquisition. Interestingly, it is thought some of the negative aspects could be explained by the participants finding the iVR environment so immersive and detailed that it becomes a distraction from the primary educational task (Pottle, 2019, Makransky et al., 2020).

Virtual Labs

There have been a number of studies conducted to date based on a virtual "lab environment". The format is appealing as it facilitates learning in a risk-free environment, allowing many scenarios to be played out multiple times that would either be too expensive or too dangerous for students to typically perform in a teaching laboratory setting (Hatchard et al., 2019). AlAwadhi et al. (2017) simulation incorporated many different types of media in the iVR framework, including virtual interactive experiments, pre-recorded lectures, mathematical simulations, 360 media tours and 360 view live streaming. Whereas Zacharia & Jong (2014) simulation compared students' cognition of electrical physics setups in an nVR simulator to the real-life lab alternative, demonstrating equivalent understanding in both study groups. Seifan et al. (2020) also compared nVR-based lab simulation to the practical experiment, however, it was framed more as a training experience. This was proven to be highly effective with more than 90% of the students deeming it to be beneficial. This aligned with their previous study that looked at the pedagogical effects a flipped learning style virtual field trip experience had on the participants before and after they attended the field trip (Seifan et al., 2019).

Outstanding Questions

Based on this review of the literature a number of outstanding research questions have been highlighted: 1) How much of an effect does an iVR experience have on learning outcomes, when compared to an nVR equivalent? 2) Does a flipped learning experience of a certain digital type aid learning when conducting the actual lab afterwards? 3) Do iVR multilingual interactions have a benefit on learner experiences compared to nVR alternatives? 4) Does a reduction in visual fidelity/detail result in better learning performance? 5) What is the difference in costs between different digital approaches versus pedagogical impact?

RESEARCH METHODOLOGY

To help address the gaps in current knowledge highlighted above, a pilot study was created based on a classic practical laboratory experiment; the three-point bending test. In the experiment, various samples (or beams) of different materials and cross-sectional geometry are tested using a Shimadzu EZ-LX Universal Tester machine. During the activity, students place the beam on supports and apply a single-point load at the center. The students then measure the beam deflection at loading intervals of their choosing. Their experimental results are then compared with their prior theoretical predictions. This experiment is taught at scale to approximately 600 students every year (Di Benedetti et al., 2022), made possible due to the many replicated copies of equipment in the department (Beck, 2022). The pedagogical benefits of this model have been discussed previously in relation to the reinforcement of learning due to the close coupling of timetabled lectures and academic program alignment (Bangert et al., 2022, Garrard et al., 2020). However, in this study, the opportunity granted by scale manifests itself in the ability to collect and analyze laboratory pedagogical data of statistical significance. In addition, the highly structured integration of a Virtual Learning Environment (VLE) based ”pre-lab” (or flipped learning) activities, can also be exploited in this research as a method of deploying variations in digital learning experiences with different levels of interactivity and fidelity.

Digital Experiences

In this proposed pilot study, cohorts of students from the 1st year Civil, Mechanical & Bio Engineering will be split into groups by typical timetable allocation (average 36 students) with

every group completing a standard summative pre-laboratory Health and Safety quiz, practical lab experience and post lab test parts based upon the three-point bending activity.
Each group will be differentiated by assigning them a variation of digital pre-lab simulated laboratory experience in between the existing test mentioned previously. One of these groups will be acting as a "control" experience with just a standard multiple-choice pre-lab activity test (Figure 1 shows the differing education workflows).

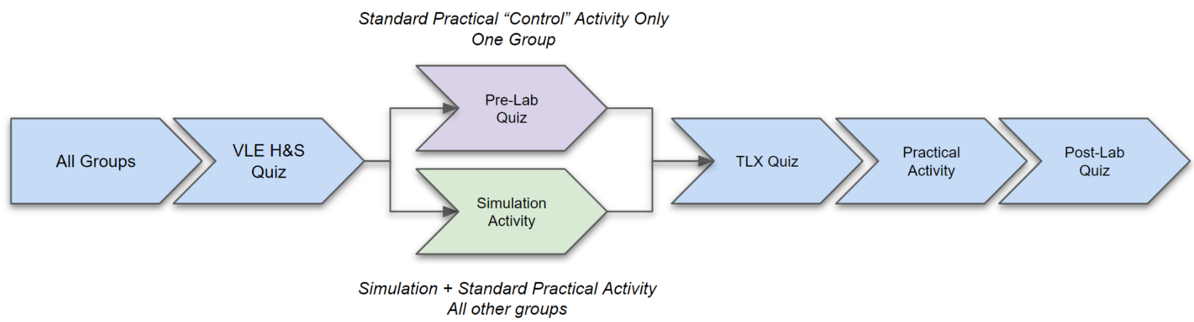

Figure 1 - Breakdown of study route per cohort

To address the question of display/simulation fidelity and the link between reinforcements of learning outcomes/memory recall (Kisker, et al. 2019), three different digital simulations have been created that allow participants to recreate the three-point bending test remotely. This includes 2D, nVR and iVR versions with varying degrees of visual immersion and detail, as this will help decouple the benefits of 2D/3D at the same time (Parong & Mayer, 2018). The financial and staff time costs in terms of development time have also been considered with each of the different simulations. Assessment in relation to the achievement of learning outcomes is discussed in the following sections.

iLabs 2D Simulation

Stanford University has developed a platform referred to as "iLab", which allows students to access data from real experiments in an interactive way. During a laboratory experiment, a number of independent variables are set and, for each combination of these, an output state is produced. The iLabs system allows instructors to upload photographic images and numerical data for every possible output state for any particular experiment. Following the upload to the system, students are able to retrieve individual output states by specifying a combination of inputs from an open-access, web-based interface, such as that shown to the left of Figure 2. While this is a finite number of possible outputs from the experiment, by uploading a large number of possible states the student user can feel in control of making decisions about the settings to used to execute the experiment.
A semi-automated hardware system was developed to record numerical data and remotely control three Raspberry Pi-based cameras, each mounted on tripods. Once the experimental area of interest is framed correctly, each camera simultaneously captures images and filenames are assigned. The digital images are then exported in the format required to directly upload to iLabs.

Web Browser-Based “Lo-Fi” Simulation

The authors developed simple, web browser-based simulations. These applications are typically referred to as “lo-fi” due to their simplicity, both in terms of their graphics and numerics. The lo-fi simulations are written using html and javascript. Experimental systems can be constructed using standard elements such as sliders, text boxes and buttons to collect input parameters and output can be displayed as text, numbers or pre-built illustrations of the apparatus. The webpage response can be programmed to replicate the physical system. The objective for this simulation method was to create digital tools that are virtually frictionless for students to access, i.e. no accounts to log into or software to download, and can be shared with other educators to reuse or adapt. In addition, there is no further hardware requirement for the construction of the lo-fi simulations, beyond a computer running a text editor and a web browser. In the three-point bending test, shown to the right of Figure 2, the beam specimen can be selected from a drop-down list, the force applied to be specimen can be infinitely adjusted using a slider and the resultant deflection is displayed. A graphical representation of the extent of deflection is displayed based on a finite number of pre-built digital images. With the standard javascript random number generator, each time a result is generated a predetermined amount of experimental error is added to the output. In fact, there is a specified amount of random and systematic error in all results to allow the digital system to more closely represent the variable output students may expect from the physical system.

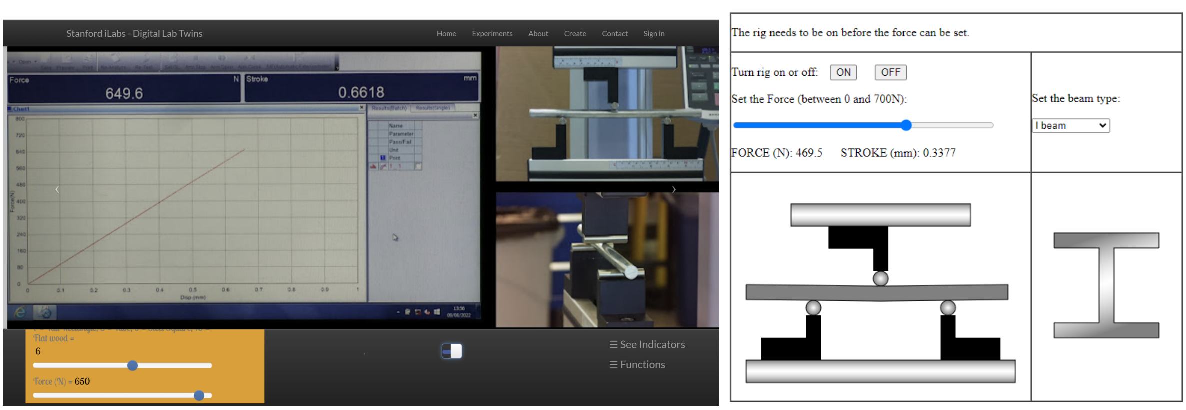

Figure 2. Typical web browser view of the (Left) iLabs simulation of three-point bending test and (right) “Lo-Fi” html based simulation

Low Fidelity - Unity iVR

In order to create a fully bespoke iVR experience it was decided that a game engine would be required in order to provide the truly immersive visual and interactive elements coupled with realistic simulations of physics. This decision was also coupled with a requirement to minimize VR hardware costs and enable an experience that is untethered (i.e. no cables linked to a PC). Based upon these considerations, the educational version of Unity 3D game engine (2020.3.34f1) was selected for use with Meta's Quest 1 & 2 headsets. This software is free for academic use and the basic Quest headsets are low-cost consumer products.

The simulation geometry was created using 3D CAD software (Solidworks, Fusion 360) based on the dimensions of the experimental apparatus, exported to the free 3D modeling software Blender and imported to the Unity Engine to create the iVR simulation. The unity simulation was designed incorporating the free Oculus XR Plugin, to enable both controller and hand tracking interactions and transferred to the Quest headsets.

The user experience of the simulation is as follows; once the program is loaded the user is presented with a scale-correct simplified version of the three-point bending apparatus in an empty boundless space (Figure 3). Using the Oculus controllers or their hands, the users can pick up any sample to test and place it into the jaws of the test machine. It should be noted that this element was considered to be an important differentiator between the simulation types as high levels of interactivity have been previously shown to increase knowledge and skills acquisition (Kyaw et al., 2019).

The force applied to the sample can be then adjusted using two large red interactable buttons and the amount of deflection read from the machine's virtual display. The beams will also deform according to the load placed upon them. The deflection is approximated visually, however, the deflection data given is accurate based on empirical data. The simulation ends when the user takes off the headset or closes the program from within the virtual environment.

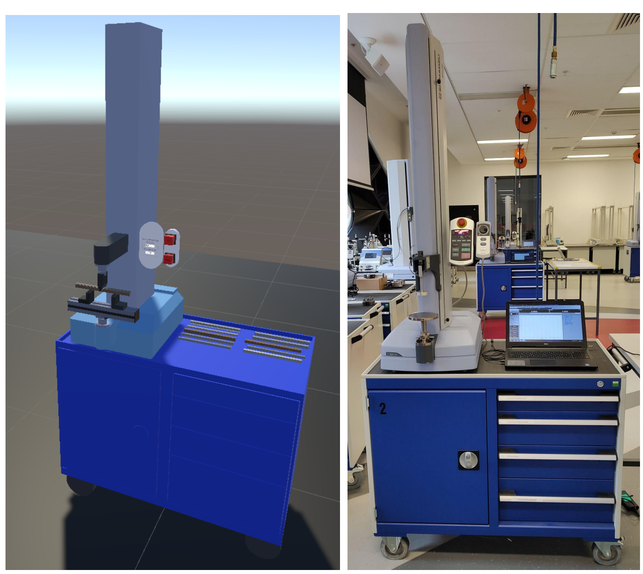

Figure 3. iVR Unity scene view with Low Fidelity model of the Shimadzu EZ-LX Universal Tester (left), High Fidelity model (center) and the real unit (right).

Simulation Costings

During this study we performed a detailed cost versus pedagogical impact assessment, as this has been previously highlighted as a potential issue in the development of XR teaching content (Kumar et al., 2021). As each of these simulations has been designed and built from the ground up, this gives a unique chance to collate data to analyze which method represents the best investment of teaching resources, taking into account the initial outlay in equipment and initial staff time for R&D and staff time for creation post R&D phase once skills were learnt (Table 1, with data based on staff time at ~£25/hr).

Table 1. Cost data for producing each form of digital simulation

Simulation	Total Hours to Create post R&D (hr)	Estimate Staff Costs post R&D	Initial R&D Time to learn skills (hr)	Estimated R&D Staff Costs for learning skills	Items Required to create Simulation	Item Costs Total
iLabs 2D Simulation	12-13	£300-£325	4	£100	PC linux, 3 Raspberry PI, 3 Camera lenses, Tripods,	£600
Web Browser Based “Lo-Fi” Simulation	8	£200	variable 2-24	£50-£600	Basic PC	£200+
Low Fidelity - Unity iVR	28.5	£712.5	49.75	£1956.25	Hi-GPU PC +VR Headset	£1000 + £400

Methods of assessment

The method of data capture proposed in this study falls into two main categories, pedagogical testing based around the student achievement of learning outcomes and the capture of the students experiential learning. In the literature, participation experience (or the more qualitative aspects) with less explicit links to the learning outcomes have been covered using–self-reported psychological assessment (Feng et al., 2018). This relates to strategies such as the use of questionnaires based on different frameworks. As this is a pilot study partly to help test the hypothesis, hone testing regimes, and with a small population size, it was decided to approach the sampling from a non-probability (theoretical/grounded theory) basis as the dataset generated would be insufficient for full statistical analysis (Cohen et al., 2007).

To streamline and pseudo-quantise the data collection we decided to adopt a combination of NASA’s Task Load Index (TLX) (NASA, 2020) (Casner & Gore, 2010) to evaluate user experience and Likert-framed questions to help differentiate factors associated with the different digital platforms. These strategies have been used successfully in other VR/multimedia comparison studies (Chittaro & Buttussi, 2015, Burigat & Chittaro, 2016). They will be highly suitable as they can be integrated into the VLE and help compare to a known standard (i.e. the traditional pre-lab) to provide concurrent validity in the analysis (Logeswaran et al., 2021).

The TLX workload assessment questions are broken down into six subscales: Mental Demand, Physical Demand, Temporal Demand, Performance, Frustration and Effort with subscale scores in the range of 1-100. This was implemented in the blackboard VLE, alongside the regular Likert questionnaire that had a 7-point scale with indicators ranging from “strongly disagree” to “strongly agree”. The Likert questions start with data collection related to prior digital media experience and finish with questions relating to measures of usability outside of workload, summarized as Prior experience with computer interfaces, Prior familiarity with VR/XR hardware, Enjoyment, Attention, Effectiveness, Usefulness, Comprehension, Ease of use, Sense of control, Sense of immersion, and Interactivity. A final unbound text box was also included to give optional written feedback.

As mentioned previously, the post-laboratory test is performed by the participants on the VLE (see Figure. 1). The structure of the test is five diagnostic summative questions, four of which are closed MCQs (a mixture of single and multiple selection types) and one that requires a value within a tolerance range.

Analysis of findings

Upon completion of the study the survey data will be analyzed and cross referenced for any correlations between the method of pre-lab digital activity and variance in the achievement of learning objectives. Any trends regarding the type of simulation fidelity/interactivity associated with that overall objective will also be considered. Depending on the quality of the data collected, a Spearman's rank-order correlation, non-parametric Mann–Whitney/Kruskal–Wallis test and Cronbach's alpha will be used to assess the findings. This data will then be compared to the overall costs and investments made to create the digital activities via an investment to pedagogical gain ratio.

CONCLUSIONS

Once the pilot study is complete and the data is analyzed it is hoped the assessment process can be further refined to ensure that the reliability and validity of the surveying is appropriate. Following this, a larger scale study is planned for the next academic year to include additional cohorts. This study may incorporate further digital simulations, to determine the effects of increased or decreased fidelity on overall student learning outcomes.

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REFERENCES

AlAwadhi, S., AlHabib, N., Murad, D., AlDeei, F., AlHouti, M., Beyrouthy, T., & Al-Kork, S. (2017, 30 Aug.-1 Sept. 2017). Virtual reality application for interactive and informative learning. 2017 2nd International Conference on Bio-engineering for Smart Technologies (BioSMART),

Bangert, K., Bates, J., Beck, S., Bishop, Z., Di Benedetti, M., Fullwood, J., . . . Woolley, R. (2022). Remote practicals in the time of coronavirus, a multidisciplinary approach. International Journal of Mechanical Engineering Education, 50(2), 219-239. https://doi.org/10.1177/0306419020958100

Beck, S. On having the right size laboratories. International Journal of Mechanical Engineering Education, 0(0), 03064190221142347. https://doi.org/10.1177/03064190221142347

Berthoud, L., & Walsh, J. (2020). Using visualisations to develop skills in astrodynamics. European Journal of Engineering Education, 45(6), 900-916. https://doi.org/10.1080/03043797.2020.1742664

Burigat, S., & Chittaro, L. (2016). Passive and active navigation of virtual environments vs. traditional printed evacuation maps: A comparative evaluation in the aviation domain. International Journal of Human-Computer Studies, 87, 92-105. https://doi.org/https://doi.org/10.1016/j.ijhcs.2015.11.004

Carruth, D. W. (2017, 26-27 Oct. 2017). Virtual reality for education and workforce training. 2017 15th International Conference on Emerging eLearning Technologies and Applications (ICETA),

Casner, S., & Gore, B. (2010). Measuring and Evaluating Workload: A Primer.

Chittaro, L., & Buttussi, F. (2015). Assessing Knowledge Retention of an Immersive Serious Game vs. a Traditional Education Method in Aviation Safety. IEEE Trans Vis Comput Graph, 21(4), 529-538. https://doi.org/10.1109/tvcg.2015.2391853

Cobb, S., Heaney, R., Corcoran, O., & Henderson-Begg, S. (2009). The Learning Gains and Student Perceptions of a Second Life Virtual Lab. Bioscience Education, 13(1), 1-9. https://doi.org/10.3108/beej.13.5

Cohen, L., Manion, L., & Morrison, K. (2007). Research methods in education, 6th ed. Routledge/Taylor & Francis Group.

Cruz, D. R. d., & Mendoza, D. M. M. (2018, 15-17 Aug. 2018). Design and Development of Virtual Laboratory: A Solution to the Problem of Laboratory Setup and Management of Pneumatic Courses in Bulacan State University College of Engineering. 2018 IEEE Games, Entertainment, Media Conference (GEM),

Dede, C. (2009). Immersive interfaces for engagement and learning. Science, 323(5910), 66-69. https://doi.org/10.1126/science.1167311

Di Benedetti, M., Day, H., & Archibald, S. (2022). Scaling up practical teaching. The one-thousand student week. European Society for Engineering Education (SEFI),

Feng, Z., González, V. A., Amor, R., Lovreglio, R., & Cabrera-Guerrero, G. (2018). Immersive virtual reality serious games for evacuation training and research: A systematic literature review. Computers & Education, 127, 252-266. https://doi.org/https://doi.org/10.1016/j.compedu.2018.09.002

Fromm, J., Radianti, J., Wehking, C., Stieglitz, S., Majchrzak, T. A., & vom Brocke, J. (2021). More than experience? - On the unique opportunities of virtual reality to afford a holistic experiential learning cycle. The Internet and Higher Education, 50, 100804. https://doi.org/https://doi.org/10.1016/j.iheduc.2021.100804

Garrard, A., Bangert, K., & Beck, S. (2020). Large-Scale, Multidisciplinary Laboratory Teaching of Fluid Mechanics. Fluids, 5(4), 206.

Goldie, J. G. (2016). Connectivism: A knowledge learning theory for the digital age? Med Teach, 38(10), 1064-1069. https://doi.org/10.3109/0142159X.2016.1173661

Hatchard, T., -Al-Amin, M., Rihawi, Z., Alsebae, A., & Azmat, F. (2019). Design and development of virtual engineering lab 15th International CDIO Conference, Aarhus University, Denmark http://www.cdio.org/files/document/file/131.pdf

Horvat, N., Martinec, T., Lukačević, F., Perišić, M. M., & Škec, S. (2022). The potential of immersive virtual reality for representations in design education. Virtual Reality, 26(3), 1227-1244. https://doi.org/10.1007/s10055-022-00630-w

Jong, M., Tsai, C.-C., Xie, H., & Wong, F. (2020). Integrating interactive learner‐immersed video‐based virtual reality into learning and teaching of physical geography. British Journal of Educational Technology, 51. https://doi.org/10.1111/bjet.12947

Kisker, J., Gruber, T., & Schöne, B. (2021). Experiences in virtual reality entail different processes of retrieval as opposed to conventional laboratory settings: A study on human memory. Current Psychology, 40(7), 3190-3197. https://doi.org/10.1007/s12144-019-00257-2

Kolb, D. (1984). Experiential Learning: Experience As The Source Of Learning And Development (Vol. 1).

Kumar, V. V., Carberry, D., Beenfeldt, C., Andersson, M. P., Mansouri, S. S., & Gallucci, F. (2021). Virtual reality in chemical and biochemical engineering education and training. Education for Chemical Engineers, 36, 143-153. https://doi.org/https://doi.org/10.1016/j.ece.2021.05.002

Kyaw, B. M., Saxena, N., Posadzki, P., Vseteckova, J., Nikolaou, C. K., George, P. P., . . . Tudor Car, L. (2019). Virtual Reality for Health Professions Education: Systematic Review and Meta-Analysis by the Digital Health Education Collaboration [Review]. J Med Internet Res, 21(1), e12959. https://doi.org/10.2196/12959

Lewis, L. H., & Williams, C. J. (1994). Experiential learning: Past and present [https://doi.org/10.1002/ace.36719946203]. New Directions for Adult and Continuing Education, 1994(62), 5-16. https://doi.org/https://doi.org/10.1002/ace.36719946203

Logeswaran, A., Munsch, C., Chong, Y. J., Ralph, N., & McCrossnan, J. (2021). The role of extended reality technology in healthcare education: Towards a learner-centred approach. Future Healthc J, 8(1), e79-e84. https://doi.org/10.7861/fhj.2020-0112

Makransky, G., Andreasen, N. K., Baceviciute, S., & Mayer, R. (2020). Immersive Virtual Reality Increases Liking but Not Learning with a Science Simulation and Generative Learning Strategies Promote Learning in Immersive Virtual Reality. Journal of Educational Psychology. https://doi.org/10.1037/edu0000473

Muller, N., Panzoli, D., Michel, G., Lagarrigue, P., & Jessel, J.-P. (2017). Learning mechanical engineering in a virtual workshop: A preliminary study on utilisability, utility and acceptability. https://doi.org/10.1109/VS-GAMES.2017.8055811

NASA. (2020). NASA TLX: TASK LOAD INDEX. NASA. https://humansystems.arc.nasa.gov/groups/TLX/

Parong, J., & Mayer, R. (2018). Learning Science in Immersive Virtual Reality. Journal of Educational Psychology, 110. https://doi.org/10.1037/edu0000241

Patle, D., Manca, D., Nazir, S., & Sharma, S. (2019). Operator training simulators in virtual reality environment for process operators: a review. Virtual Reality, 23. https://doi.org/10.1007/s10055-018-0354-3

Pottle, J. (2019). Virtual reality and the transformation of medical education. Future Healthc J, 6(3), 181-185. https://doi.org/10.7861/fhj.2019-0036

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/https://doi.org/10.1016/j.compedu.2019.103778

Schofield, D. (2012). Mass Effect : A Chemical Engineering Education Application of Virtual Reality Simulator Technology. Journal of Online Learning and Teaching, 8, 63-78.

Seifan, M., Dada, D., & Berenjian, A. (2019). The effect of virtual field trip as an introductory tool for an engineering real field trip. Education for Chemical Engineers, 27, 6-11. https://doi.org/https://doi.org/10.1016/j.ece.2018.11.005

Seifan, M., Robertson, N., & Berenjian, A. (2020). Use of virtual learning to increase key laboratory skills and essential non-cognitive characteristics. Education for Chemical Engineers, 33, 66-75. https://doi.org/https://doi.org/10.1016/j.ece.2020.07.006

Soliman, M., Pesyridis, A., Dalaymani-Zad, D., Gronfula, M., & Kourmpetis, M. (2021). The Application of Virtual Reality in Engineering Education. Applied Sciences, 11(6), 2879.

Suh, A., & Prophet, J. (2018). The state of immersive technology research: A literature analysis. Computers in Human Behavior, 86, 77-90. https://doi.org/https://doi.org/10.1016/j.chb.2018.04.019

Vergara, D., Antón-Sancho, Á., Extremera, J., & Fernández-Arias, P. (2021). Assessment of Virtual Reality as a Didactic Resource in Higher Education. Sustainability, 13(22), 12730.

Zacharia, Z., & Jong, T. (2014). The Effects on Students' Conceptual Understanding of Electric Circuits of Introducing Virtual Manipulatives Within a Physical Manipulatives-Oriented Curriculum. Cognition and Instruction, 32. https://doi.org/10.1080/07370008.2014.887083

Zhang, Y., Chen, J., Miao, D., & Zhang, C. (2018). Design and Analysis of an Interactive MOOC Teaching System Based on Virtual Reality. International Journal of Emerging Technologies in Learning (iJET), 13, 111. https://doi.org/10.3991/ijet.v13i07.8790

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Edward Browncross is a software developer with over 10 years experience. He has worked as a software engineer working on cutting-edge remote labs at other HE institutions (the Open University and the University of Bradford). He supports MEE and the wider Engineering Faculty in delivering best-in-class teaching quality, student support and staff wellbeing by building innovative digital solutions to the problems staff and students encounter day-to-day. This includes everything from workflow automation and data warehousing to virtual reality and remote labs.

Harry Day is a chartered engineer with a background in structural/mechanical engineering for the offshore wind industry, and a PhD in aerodynamics. He is the Director of Education for the Department of Multidisciplinary Engineering Education (University of Sheffield) where he also teaches structural engineering labs for numerous courses across the faculty. Harry's key interests include the development of teaching assistant teams, strategies for engaged learning, and the student voice.

Andrew Garrard is Professor of Engineering Education and Head of the Department of Multidisciplinary Engineering Education. He holds a degree in Mechanical Engineering from the University of Sheffield, where he also conducted his PhD research into regenerative fuel cell systems for energy storage. In 2008 he took up a lectureship at Sheffield Hallam University. In 2009, he was promoted to senior lecturer and was responsible for leading the thermofluids teaching group. He rejoined the University of Sheffield as part of Multidisciplinary Engineering Education in 2015, helping to set up the new department in the role of Departmental Director of Learning and Teaching followed by Deputy Head of Department. He took the position of HoD of Multidisciplinary Engineering Education in 2022.

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