Impact of Immersive Extended Reality for Online Engineering Training

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Abstract: In almost every facet of education both in-person and online streams exist. This is true for business, science, humanities, and even medicine, in many instances. Even engineering offers some content online but is stymied by the inability to truly deliver an online laboratory experience. As a result, critical training content is lost to the online student. SETU Carlow and DCU have partnered to deliver a novel, state-of-the-art, off-campus laboratory education experience. This preliminary study investigates the benefits of an Immersive Extended Reality (I-XR) content for training undergraduate students to use high-end, complex, expensive test equipment in a safe and supportive environment. It was found that a broad range of students were able to translate I-XR learnings directly to successful usage of this test equipment, suggesting that further development and expansion of these platform services are strongly advised.

Keywords; engineering education research, pedagogy, transformative technologies, Extended Reality, STEM, Immersive Content.

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1. INTRODUCTION

Online STEM programmes have always been very popular. The one main problem has been delivering a true laboratory experience to an off-campus learner cohort, thus necessitating on-campus sessions. In the post-pandemic era, a lot of attention has remained on the experiential gulf between an on-campus and an off-campus learning experience. The former, being the traditional route to education, has dominated in many conversations as the student-preference. However, the longevity of the COVID pandemic has highlighted an urgent need to address this rather challenging situation. It is widely accepted that hands-on experiences are essential in STEM programmes, as they enhance problem-solving skills, provide practice for real-world predicaments, and give learners hands-on experiences with the selected tools and equipment. The premise is not to replace traditional didactic methods, such as blended learning environments, but to enhance the learner experience through immersive and realistic 3D experiences. Research in this area has been ongoing for a number of years and the summations have been generally positive. (Slater, 2018) states that, although XR hardware has been available since the 1980s, accessibility and affordability kept it out of the mainstream. However, with the evolution of the Oculus systems in 2013, the 3D virtual world became accessible to the general population in terms of availability, usability, and economic feasibility (Hodgson, et al., 2015; Olmos, Cavalcanti, Soler, Contero, & Alcañiz , 2018). Despite the exciting potential of this technology, adaptation for engineering purposes has been slow and has mainly focussed on pedagogical supports, rather than a revolutionary tool (Hodgson, et al., 2019). Although Immersive Suites have opened in numerous locations around Ireland, substantial research must be undertaken to guide and support the embedding of this advanced tool, in an appropriate and progressive manner.

The aim of this research, of which only results of a preliminary study are herein reported, is to

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study the virtual delivery of laboratory-based training content and to demonstrate the potential for an on-campus laboratory experience in an off-campus environment. Equipment unfamiliar to the students was selected, so that reported new learnings, enhanced student engagement, and improvements in knowledge retention could not be attributed to prior knowledge. Furthermore, it is planned that the undertaken analysis will better inform online teaching and learning strategies and promote productive active learning experiences in a blended learning environment. This is, however, a complex task as the experiences are highly personalised (each student is very different) so the compositional development requires a content design that stimulates, rather than dissuades, stakeholder engagement, supported by iterative analysis and stepwise enhancements.

1.1 Online Education and Knowledge Retention

A truly considered, scaffolded, teaching strategy requires multi-layered analysis: learning theories and strategies, cognitive styles, dissemination modes, student history, demographic, social stratification, possibly even gender and age, group dynamics and interactions, synchronous/asynchronous content (Güryay, 2016). In terms of pure research, it is acknowledged that the outputs of this pedagogical exploration are only truly relevant to the specific group of students involved in the pilot programme. It is, however, hoped that this study will lead to an increase in content-digitisation, resulting in reliable improvements in student interaction, enhanced topic immersion communed with a transition from surface to deep learning, and increased levels of comprehension and knowledge retention. (Khalil & Elkhider, 2016) outline a three-tier memory process for long-term knowledge retention. Information starts with perception (sensory memory) and then passes to working memory (if the student is paying attention). Knowledge retention depends on the final transfer of the information to long-term memory, but this must occur quickly as working memory is limited in terms of endurance and capacity (Baddeley, 2003). Working memory (or episodic buffer) is assumed to be a limited-capacity temporary storage system that can integrate information from a variety of sources (Baddeley, 2000). These processes, particularly working memory which facilitates short-term multimodal storage, must underpin module design (Merrill, 2002).

1.2 Offsite Technological Revolution

In recent years, scholarly and pedagogical attention has increasingly focussed on the coaction between digital and physical environments. Modern pedagogical developments in this area are progressively moving towards digitisation – both in terms of content delivery and classroom format. In other words, digitisation technologies are gaining more mindshare within educational institutions. According to Gartner's Hype Cycle for Education Toolbox (Lowendahl, 2016), for example, digitisation of lecturing tools is fast becoming mission-central for education institutes, whilst remaining the responsibility of all affected stakeholders (staff, students, parents, communities, industry). The introduction-to-obsolescence cycle of the constant stream of new technologies is illustrated in

Figure 1. The key to achieving long-term technological success is about embracing an ecosystem of relevant technologies which support a prioritised strategy (Lowendahl, 2016). Extended Reality, as a holistic vision, is a technology with in-built long-term pedagogical relevance which can support student-centric learning in a unique and exciting way.

Students are a key stakeholder in these pedagogical developments, so it is imperative that learning activities should involve the students' collaborative construction of classroom artefacts (Abrahamson & Wilensky, 2005). This teaching concept is the basis of active learning, which benefits from a multi-modal (blended) learning approach and broadens potential limitations of

STEM to a more embracing STEAM structure*. Delivery of a learning experience can be manipulated in terms of a *continuum of similarity*, to improve retention and recall (Jones & Macken, 2015); one such technique which is now being widely studied, is Extended Reality.

Of the many important elements identified from this critical analysis but the elements most relevant to this research link the environment and technologies.

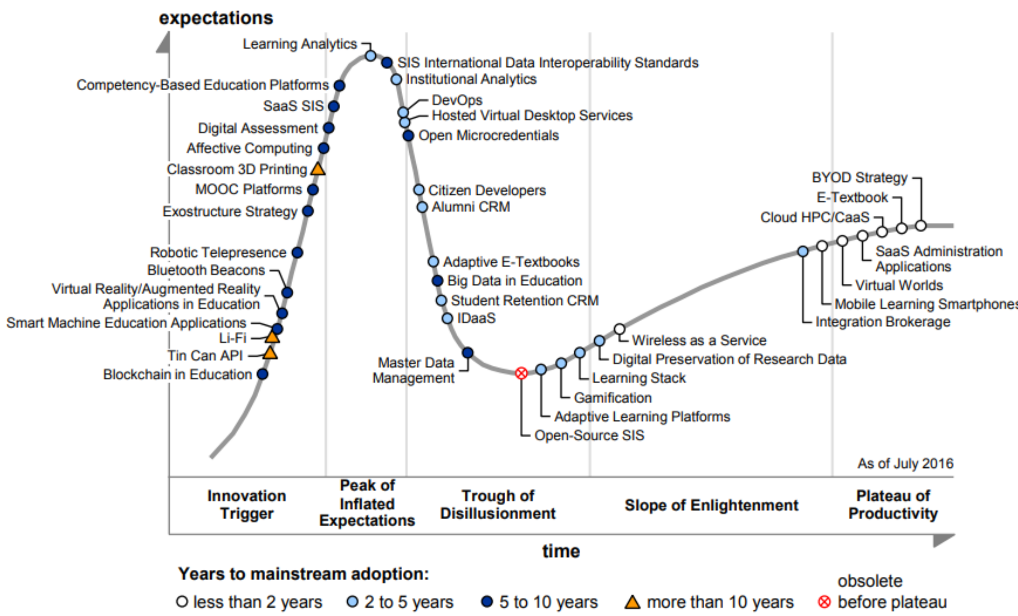

Figure 1 Hype Cycle for Education (Lowendahl, 2016)

Environment: Both (Carless, 2015, p. 192) and (Thorpe, 1995, pp. 175-184) emphasise that learning is dynamic, and in many ways unpredictable, thus necessitating a pedagogical approach which balances appropriate structure for novice learners, with enough flexibility to accommodate self-management. This self-management empowers the student and promotes a positive dialogic relationship between lecturer and student (Somba, Obura, Itevete, & Njuguna, 2016; Botas, 2004).

Technologies: concept visualisation is critical in STEM programmes – this can be substantially improved through immersive technology (Fogarty, McCormick, & El-Tawil, 2018). (Matukhin & Zhitkova, 2015) commend the use of familiar modern accessible internet/online tools to enhance the blended learning experience and student engagement. While (Singh, 2003) studied, and achieved very positive results in an industrial environment, a methodical approach to designing a blended learning experience. As demonstrated, appropriate methods of embracing technology have been shown to promote better learning and knowledge retention for the affected students.

2. PRELIMINARY RESEARCH

SETU Carlow and DCU have partnered to deliver a novel, state-of-the-art, off-campus laboratory education experience, in a project funded by the HEA HCI PIII call† (2020). The programme is

*STEM explicitly focuses on engineering & scientific concepts whereas STEAM investigates the same concepts but does this through inquiry and problem-based learning methods used in the creative processes (theconversation.com).
† The Higher Education Authority (HEA) Human Capital Initiative (HCI) is an Irish government-funded initiative which seeks to promote innovative and responsive models of programme delivery, and to enable the higher education system to respond rapidly to changes in both skills requirements and technology. There are three Call

new, and piloting of both the content and the Immersive Extended Reality (I-XR) experiences is ongoing, with some preliminary results presented in this paper. The I-XR app is designed to train learners on the configuration and use of a 100 kN Walter+Bai Dynamic Test System, Model LFV 100-HH (Figure 2). It is predicted that by undertaking multiple, iterative, engagements with the developed I-XR App, each learner will develop muscle-memory in terms of successfully using the test equipment; a technique successfully used in other learning environments (Maddox & Campbell, 2017) As stated by Maddox et al., pilots have long depended on simulators for their early-stage training – which proves that there is a significant transfer from I-XR training to real world skills development.

Figure 2 Images of a) the Fatigue Test rig, b) the Virtual Reality experience.

2.1 Research Overview

A group of 30 undergraduate students, all from the same programme and year, were offered the opportunity to engage with a newly developed I-XR experience. Each student was provided with an Oculus Quest 2 onto which the app needed to be installed. Participants were required to complete a consent form, and then segments of a questionnaire. The first part of the questionnaire gauged their understanding of the fatigue testing protocols, the second part reviewed their pre- and post- event I-XR experience. The event occurred over a period of approximately 4 hours. The learner cohort was approximately 12% female, which is below the national *female students in engineering education in Ireland* average of 20%.

2.1.1 Formative Feedback and Evaluation Questionnaire

The participants were required to complete sections of the questionnaire at different stages during the pilot. A total of 10 open-ended questions were to be answered.

- Section 1 (3 questions) was designed to gauge the knowledge of the participant on fatigue testing prior to participation in the training.
- Section 2 (7 questions) targeted the knowledge of the students on completion of the I-XR Training experience, to flag any previous experience with I-XR systems and to measure the learner's personal experience of the training programme. Learners were requested to provide feedback on the overall experience in comparison to an in-laboratory experience, and to identify elements of the training that were good and "could be better".

Responses were then ranked from 1 - 5, with 1 reflecting the least positive experience and 5 the most positive.

2.2 Analysis and Discussion

It has been shown in multiple published studies that STEM students experienced much higher learning gains using I-XR training. (Halabi, 2020) showed that I-XR improved problem-solving

Pillars under which funding can be sought: Pillar 1 – Full-Time Graduate Conversion Courses, Pillar 2 – Additional Places on Existing Full-Time Undergraduate Provision, **Pillar 3** – Innovation and Agility.

skills and enhanced learning outcomes. Likewise, (Akbulut, Catal, & Yildiz, 2018) found that students who underwent an I-VR experience that focused on software engineering principles scored 12% higher than students who did not undergo I-VR learning. As a result, it was deemed appropriate to capture the success of the I-XR training using questionnaire responses. The experiences of the participants were therefore documented via questionnaire, in addition to some later unstructured conversations. The questions were constructed to query the existing knowledge and the experience.

	Pre-VR Knowledge			Post-VR Knowledge				
	Q1	Q2	Q3	Q1	Q3	Q4	Q5	Q6
A1	8.3%	4.2%	0.0%	16.7%	36.4%	42.9%	47.4%	50.0%
A2	0.0%	8.3%	4.2%	0.0%	31.8%	33.3%	42.1%	27.3%
A3	0.0%	0.0%	0.0%	12.5%	9.1%	0.0%	5.3%	18.2%
A4	8.3%	0.0%	4.2%	4.2%	13.6%	14.3%	0.0%	0.0%
A5	79.2%	83.3%	87.5%	62.5%	4.5%	4.8%	0.0%	0.0%

Table 1 Tabulated interpreted results from the questionnaires (selected responses only).

Pre-VR Knowledge: Purpose of the Fatigue Test (Q1), How is it performed (Q2), and List 5 elements of a Fatigue Test Rig (Q3), Experience of App (Q3).
Post-VR Training Experience: Have you previously used a VR headset (Q1); How does app compare to an in-lab experience (Q4); What new experiences were a result of the VR app (Q5); Is the VR Training effective (Q6).
These questions probed the experience of the learner before using the Oculus and again queried the quality and relevance of their I-XR experience. Questionnaires were completed prior to departure from the event space, to ensure that they represented only the opinion/experiences of the specific learner and did not become diluted through post-departure conversations. The responses to the various questions were ranked - 1 (Best/Most Relevant) to 5 (Worst/Least Relevant). This facilitated numerical analysis of the generated quantitative data. Using this data, including that displayed in **Error! Reference source not found.**, the key findings were as follows:

1. All of the participants used Smart Phones and had access to IT technologies, such as computers. However, over 60% of the participants had never previously used an I-XR headset or any form of immersive virtual training experience. This aligns well with many of the publications on this topic, in which the lack of available training content belies the positive indicators of its potential.
2. Over 80% had no knowledge or understanding of the fatigue test. This meant that the vast majority of the participants were engaging in training with no prior knowledge of either the test or the equipment. Any knowledge capture during this training could then be attributed to the training app. Subsequent unstructured interviews with a selection of the participants showed new knowledge had been gained on this test and the test setup. Similar to (Akbulut, Catal, & Yildiz, 2018), the positive impact of I-XR training was immediate and measurable.
3. Approximately 70% of the participants could see the value in the training and understood / could correctly adjudicate its purpose and relevance.
4. Over 75% of the participants found the training app to be either very enjoyable or excellent. Thus, showing that, in the event of a general rollout, the students would actively and positively engage in its usage. This is a critical necessity for the successful development of this state-of-the-art training content.

The results of this pilot align very well with previously published studies on this subject, across a variety career spectra. Further work is planned in terms of immersive training content and experiential quality.

2.3 Conclusions

Although only preliminary data have been generated so far, the analysis of this data is very positive. Further development of the I-XR App, alongside the introduction of 360° Immersive Content (demo videos) will enhance both the appeal of this novel technology and its applicability in online experiential delivery of STEM laboratory training content. Further pilots, engaging Level 7-9 learners, along with a varied selection of industrial trainees.

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4. REFERENCES

Abrahamson, D., & Wilensky, U. (2005). The Stratified Learning Zone: Examination of the Pros and Woes of Collaborative-Learning Design in Demographically-Diverse Mathematics Classrooms. In D. Y. (Discussant) (Ed.), *Annual Conference American Educational Research Association*, (p. 28). Montreal. Retrieved March 2019

Aguado, D., Arranz, V., Valera-Rubin, A., & Marin-Torres, S. (2011). Evaluating a blended-learning program on developing teamwork competence. *Psicothema, 23*(3), 356-361.

Akbulut, A., Catal, C., & Yildiz, B. (2018, April 08). On the effectiveness of virtual reality in the education of software engineering. *Computer Applications in Engineering Education, 26*(4), 1-10. doi:10.1002/cae.21935

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423. doi:10.1016/S1364-6613(00)01538-2

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423. doi:10.1016/S1364-6613(00)01538-2

Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature Reviews Neuroscience, 4*(10), 829-839.

Bernhard, J., & Baillie, C. (2013). Standards for quality of research in engineering education. In R. Hadgraft (Ed.), *Proceedings of the Research in Engineering Education Symposium. 1*, p. 481. Putrajaya: Research In Engineering Education Network. Retrieved March 2019

Bhattacharyya, G., & Bodner, G. M. (2005). "It Gets Me to the Product": How Students Propose Organic Mechanisms. *Journal of Chemical Education, 82*(9), 1402-1407. doi:10.1021/ed082p1402

Botas, P. C. (2004). Students' perceptions of teachers' pedagogical styles in Higher Education. *Educate ~ The Journal of Doctoral Research in Education, 4*(1), 16-30.

Brunton, E., Cleary, J., Doyle, J., O'Mahony, L., & Trant, Í. (2006). *Successful Transition to Third Level Education: First Year Induction Week Research.* Retrieved March 2019, from http://www.ittralee.ie/en/pdf/SuccessfulTransitiontoThirdLevelEducation.pdf

Carless, D. (2015). *Excellence in university assessment: learning from award-winning practice* (1 ed.). New York: Routledge.

Donaldson, L. (2014). Integrating Web 2.0 Learning Technologies In Higher Education: The Necessity, The Barriers And The Factors For Success. *All Ireland Journal of Teaching and Learning in Higher Education (AISHE-J), 6*(3), 2021-20222.

Evans, C. (2013). Making Sense of Assessment Feedback in Higher Education. *Review of Educational Research, 83*(1), 70–120. doi:10.3102/0034654312474350

Fogarty, J., McCormick, J., & El-Tawil, S. (2018). Improving Student Understanding of Complex Spatial Arrangements with Virtual Reality. *Journal of Professional Issues in Engineering Education and Practice, 144*(2), 04017013. doi:10.1061/(ASCE)EI.1943-5541.0000349

Frache, G., Nistazakis, H., & Tompras, G. (2018). Constructing Learning-by-Doing Pedagogical Model for Delivering 21st Century Engineering Education. *Advances in Science, Technology and Engineering Systems Journal, 3*(1), 115-124.

Güryay, B. (2016). The Relationship between Learning Modalities and Perceived Self-regulation Levels Procedia. *Social and Behavioral Sciences, 232*, 389-395. doi:https://doi.org/10.1016/j.sbspro.2016.10.054

Hake, R. R. (1998, January). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64-74. doi:10.1119/1.18809

Halabi, O. (2020). Immersive virtual reality to enforce teaching in engineering education. *Multimedia Tools and Applications, 79*, 2987–3004. doi:10.1007/s11042-019-08214-8

Hartley, J. (1998). *Learning and Studying: A Research Perspective* (1st ed.). London: Routledge.

Hodgson, E., Bachmann, E. R., Vincent, D., Zmuda, M., Waller, D., & Calusdian, J. (2015). WeaVR: a self-contained and wearable immersive virtual environment simulation system. *Behavior Research Methods, 47*, 296-307. doi:10.3758/s13428-014-0463-1

Hodgson, P., Lee, V. W., Chan, J. C., Fong, A., Tang, C. S., Chan, L., & Wong, C. (2019, February 20). *Immersive Virtual Reality (IVR) in Higher Education: Development and Implementation* (Vol. Augmented Reality and Virtual Reality The Power of AR and VR for Business). (M. C. Dieck, & T. Jung, Eds.) Cham, Switzerland AG: Springer Nature Switzerland AG. doi:10.1007/978-3-030-06246-0_12

Jones, G., & Macken, B. (2015). Questioning short-term memory and its measurement: Why digit span measures long-term associative learning. *Cognition, 144*(November), 1-13.

Khalil, M. K., & Elkhider, I. A. (2016). Applying learning theories and instructional design models for effective instruction. *Advances in Physiology Education, 40*(2), 147-156. doi:10.1152/advan.00138.2015

Leonard, J., & Guha, S. (2001). Education at the Crossroads: Online Teaching and Students''Perspectives on Distance Learning. *Journal of Research on Technology in Education, 34*(1), 51-57.

Lowendahl, J.-M. (2016, July 1). *Hype Cycle for Education, 2016.* Retrieved February 2019, from https://www.cfisd-technologyservices.net/uploads/5/1/5/7/51575175/l_v_gartner_-_2016_06_-

_hype_cycle_for_education_2016.pdf

Lowery, J. W. (2001). The Millennials Come to Campus. *About campus, 6*(3), 6-12. doi:10.1177/108648220100600303

MacCraith, B. (2016, March 29). *Irish Times: Why we need more T-shaped graduates.* Retrieved January 2019, from https://www.irishtimes.com/news/education/why-we-need-more-t-shaped-graduates-1.2584765

Maddox, W. T., & Campbell, P. (2017, December 20). *Muscle Memory and the Brain Science Behind VR.* Retrieved August 2022, from Training Industry: https://trainingindustry.com/articles/learning-technologies/muscle-memory-and-the-brain-science-behind-vr/

March, T. (2016, April 26). *Starting An Education Revolution: The Role of Innovation.* Retrieved April 2019, from Education Technology Solutions: https://educationtechnologysolutions.com/2016/04/starting-an-education-revolution-the-role-of-innovation/

Matukhin, D., & Zhitkova, E. (2015). Implementing Blended Learning Technology in Higher Professional Education. *Procedia - Social and Behavioral Sciences, 206*(17), 183-188. doi:10.1016/j.sbspro.2015.10.051

Merrill, M. D. (2002). First principles of instruction. *Educational technology research and development, 50*, 43-59.

Nicol, D. (2010). From monologue to dialogue: improving written feedback processes in mass higher education. *Assessment & Evaluation in Higher Education, 35*(5), 501-517.

O'Dwyer, A., & Childs, P. (2014). Organic Chemistry in Action! Developing an Intervention Program for Introductory Organic Chemistry To Improve Learners' Understanding, Interest, and Attitudes. *Journal of Chemical Education, 91*(7), 987-993. doi:10.1021/ed400538p

Olmos, E., Cavalcanti, J. F., Soler, J.-L., Contero, M., & Alcañiz , M. (2018). Mobile Virtual Reality: A Promising Technology to Change the Way We Learn and Teach. *Mobile and Ubiquitous Learning*, 95-106. doi:10.1007/978-981-10-6144-8_6

Rutherford, S. M., Limorenko, G., & Shore, A. (2016). Correlations between learning styles and perceptions of Collaborative Learning in Higher Education. In C. A. Shoniregun, & G. A. Akmayeva (Ed.), *Ireland International Conference on Education (IICE-2016)* (pp. 73-78). Dublin, Ireland, 24-26 October 2016: Infonomics Society. doi:DOI: 10.2053/IICE.2016.0014

Singh, H. (2003). Building Effective Blended Learning Programs. *Educational Technology, 43*(6), 51-54.

Slater, M. (2018). Immersion and the illusion of presence in virtual reality. *British Journal of Psychology, 109*, 431-433. doi:10.1111/bjop.12305

Somba, A., Obura, G., Itevete, B., & Njuguna, M. (2016). The use of Feedback to Engage and Empower Students to Self Regulate their Own Learning. *Mara Research Journal of Humanity & Social Sciences, 1*(1), 1-12.

Spiller, D. (2014, January). *Assessment: Feedback to Promote Student Learning.* Retrieved July 2018, from University of Waikato:

https://www.waikato.ac.nz/__data/assets/pdf_file/0008/352871/Assessment_-Feedback-to-Promote-Student-Learning.pdf

Thorpe, M. (1995). The Challenge facing Course Design. In F. Lockwood (Ed.), *Open and Distance Learning Today* (1st ed., p. 396). London: Routledge. doi:10.4324/9781315004273