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COMPARING XR AND DIGITAL FLIPPED METHODS TO MEET LEARNING OBJECTIVES (RESEARCH-PRACTICE)

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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 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 exposed to one of three forms of digital "pre-lab" laboratory simulation and their academic performance assessed following a physical laboratory. The three forms are a 2D photography "iLabs" simulation, a web-based "low fidelity" simulator and a Unity based immersive Virtual Reality (iVR) lab simulator. All three methods are based on the same empirically derived data. As a control, another group of students will not receive a pre-lab simulation, just a standard pre-lab quiz. The study methods will be tested in a small scale preliminary study with a smaller cohort of students ahead of the main work to optimize the experience.

This research 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.

1 INTRODUCTION

Extended Reality or XR is a label commonly used to categorize different types of immersive technologies and concepts. Within this field, there is; 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. XR technology has had a resurgence in recent decades due to progress and investment in the associated hardware and software. Alongside commercial and domestic interest, there has been an explosion of interest in XR within Higher Education (HE). 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, workshop health and safety, fluid mechanics, electrical theory and chemical/biological simulation.

1.1 Educational Approaches

One reason XR has been vigorously pursued in HE is the many perceived benefits offered to 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 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.

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. 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) can be designed into a VR experience.

1.2 2D, 3D & Immersion

Following the description in Suh and 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. Immersive VR (iVR) - These systems require users to wear headsets 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 typically cannot provide (Horvat et al. 2022). However, this finding is not compared to that of a true 2D diagrammatic benchmark and Berthoud and Walsh (2020) also showed his nVR program proved effective at demonstrating 3D complex systems. 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. Based on the postulation by Dede (2009), 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, Gruber, and Schöne (2021) suggests that iVR could have a greater impact (compared to nVR) due to the experience imprinting on the users' autobiographical memory. The sense of immersion is considered to be the biggest advantage that iVR experiences have compared to transitional teaching methods like 2D videos.

2 METHODOLOGY

2.1 Outstanding Questions

Based on this literature review a number of outstanding research questions have been highlighted: 1) How much of an effect does an iVR experience have on learning outcomes 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?

2.2 Study Basis

To help address these gaps, a study was created based on a classic practical laboratory experiment; the three-point bending test. In the experiment, beams of different materials and cross-sectional geometry are tested using a Shimadzu EZ-LX Universal Tester machine. Students place the beam on supports, apply a single-point load at the center, and measure the beam deflection at loading intervals. This experiment is taught at scale to approximately 1000 students every year. The opportunity granted by this scale of cohort 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, means different digital experiences can be deployed efficiently to students.

2.3 Digital Experiences

In this proposed study, cohorts of students from the 1st year Civil, Mechanical & Bio Engineering will complete a standard pre-laboratory Health and Safety quiz, practical three-point bending lab activity and post lab test. Each group will be differentiated by assigning them a different digital pre-lab, described previously. One of these groups will be acting as a "control" experience with a standard pre-lab quiz, this option will also be default for students who don't opt in to the study as this represents the existing format of the lab activity. To address the question of display/simulation fidelity and the link between reinforcements of learning outcomes/memory recall, 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. The financial and staff time costs in terms of development 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 Fig. 1. 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 be used to execute the experiment.

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 easy to access, i.e. log-ins or software needed, 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 Fig. 1, the beam specimen can be selected from a drop-down list, the force applied 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.

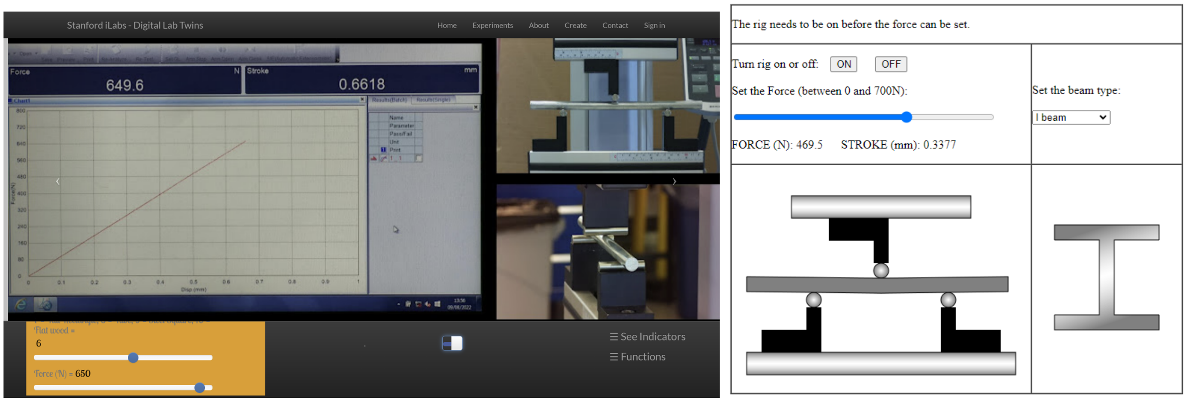

Fig. 1. Typical web browser view of the (Left) iLabs simulation of three-point bending test and (right) “Lo-Fi” html based simulation

Low Fidelity - Unity iVR: To create a fully bespoke iVR experience it was decided that a game engine would be required to provide the truly immersive visual and interactive elements coupled with realistic simulations of physics. The educational version of Unity 3D game engine 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, processed by the 3D modeling software Blender and imported to the Unity Game Engine. 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 (Fig. 2). Using the Oculus controllers or their hands, users can pick up any sample to test and place it in 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.

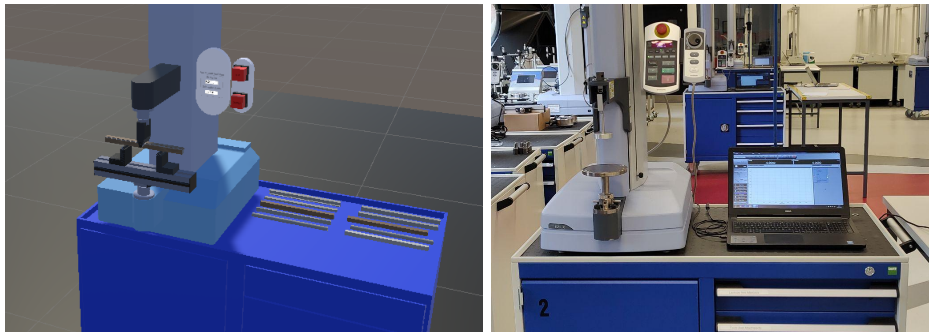

Fig. 2. iVR Unity scene view with Low Fidelity model of the Shimadzu EZ-LX Universal Tester (left), and the real unit (right).

2.4 Simulation Costings

As each of the simulations were built in-house, this presented a unique opportunity to analyze which method represents the best value in terms of education benefit versus financial/time investment. Thus, a detailed assessment accounting for initial costs, staff time for R&D and staff time for activity creation (post R&D) once skills were learnt was created (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	£325	4	£100	Raspberry PI, 3 Cameras lenses, tripods	£600
Web Browser Based "Lo-Fi" Simulation	8	£200	20	£500	Basic PC	£200+
Low Fidelity - Unity iVR	28.5	£712.5	80	£2000	Hi-GPU PC +VR Headset	£1000 + £400

2.5 Methods of assessment

The method of data capture proposed for the main study and utilized here for the preliminary study, falls into two main categories; pedagogical testing (student achievement of learning outcomes), and student's 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 the preliminary study only includes 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. To streamline and pseudo-quantise the data collection a combination of NASA's Task Load Index (TLX) methodology, to evaluate user experience, and Likert-framed questions, to help differentiate factors associated with the different digital platforms, was adopted. These strategies have been used successfully in other VR/multimedia comparison studies (Burigat and 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. 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 with a 7-point scale 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. The post-laboratory test is performed by the participants on the VLE. 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.

2.6 Analysis of findings

Upon completion of the main-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. 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.

3 PRELIMINARY STUDY RESULTS and DISCUSSION

Due to low engagement in the preliminary study (5 of 58 participants), only a limited analysis could be performed on the VR pre-lab activity (5 datasets). Within the TLX data, there was variation in how participants perceived the same activity, with each subscale average showing the following (scale 0-100): Mental Demand 31, Physical

Demand 33, Temporal Demand 30, Performance 13, Frustration 21 and Effort 24. This shows that there was generally low frustration and low effort experienced with the task, yet moderate mental demand. These are indicators that the activity was fun and engaging, and that the methodology is reasonable. Interestingly, the largest individual variance was found in ‘physical demand’ experienced. As the physical strain was small in practice as there was no physical mass to move other than the controller/headset itself, this highlights a possible issue in the framing of the question “*How much physical activity was required*”. The likert data showed a favorable experience was had by all participants, with 60% and 54% “Strongly” agreeing that the simulation was easy to use and offering “Excellent” inactivity. Crucially, 39% and 50% of respondents said it was “useful in their understanding of the subject” in the “Strongly Agree” and “Agree” fields respectively. One student commented in the feedback “*Hopefully more labs in the future have VR prelabs to complete vs the standard prelab*”, which is very positive. These findings are cautiously considered as provisional, as no post lab data could be collected to examine the educational value of the activity (compared to the baseline), the sample size limited and original comparison premise could not be tested. Aside from the results data, the pilot highlighted several ways that delivery and communication (with students participants) can be improved for the next study. A much larger cohort will be engaged, and a more streamlined version of the survey will also be used to improve the response rates for the main study.

4 SUMMARY and ACKNOWLEDGMENTS

The preliminary study has been effective in highlighting areas that need honing before the main study takes place. Amendments to the delivery of material and communication with student participants will ensure the reliability and validity of the survey data gathered. The final study may incorporate further digital simulations, to determine the effects of increased or decreased fidelity on overall student learning outcomes.

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