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LARGE GROUP AR LAB EXPERIMENT SIMULATION TO INCREASE STUDENT PARTICIPATION

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ABSTRACT

This paper presents the design and implementation of a novel Augmented Reality (AR) experience for teaching engineering students the principles of elastic beam theory. Traditionally, this concept has been conveyed through physical laboratory experiments. However, at Sheffield University's Department of Multidisciplinary Engineering Education, such setups require extensive preparation by technical staff

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to accommodate large student cohorts. This translates to lengthy turnaround times between activities and hinders efficient laboratory scheduling.

Furthermore, the existing equipment similarity with previous sessions earlier in the semester contributes to lower student engagement and participation compared to other experiments utilizing different sets of apparatus. The proposed AR solution addresses these shortcomings by eliminating the need for a complex physical setup within the lab. Students only require an AR headset and a designated 2x2 meter flat space. Initial data suggests a significant increase in student participation and satisfaction with this AR approach.

Beyond its logistical advantages, the AR simulation holds immense potential for enriching learning experiences. It allows for the rapid manipulation of material properties, beam cross-sections, and data overlays in innovative ways, exceeding the capabilities of traditional equipment. This enhanced flexibility paves the way for a more dynamic and engaging learning environment for engineering students.

1 INTRODUCTION

The landscape of Higher Education (HE) is undergoing a transformation fueled by the burgeoning adoption of Extended Reality (XR) technologies. Encompassing a spectrum of immersive experiences, XR incorporates Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). VR creates interactive, computer-generated environments, while AR overlays digital information onto the physical world. MR, meanwhile, seamlessly blends elements of both. Recent advancements and investments in hardware and software have propelled XR technology into a period of significant resurgence, with its applications extending far beyond commercial and domestic use. Meta reviews have indicated a year-on-year increase in published papers on this topic within the field of education, often with a large focus on teaching practical-procedural skills in engineering (Radianti et al. 2020) and this trend has continued up to the year of writing (Lin et al. 2024).

Meta-reviews of recent studies of XR technologies in HE have shown encouraging patterns, with VR increasing student engagement across a number of measures (Lin et al. 2024) with one meta-review focusing on Engineering showing impact on student satisfaction in 96% of cases (Vicente dos Anjos et al 2022)

In previous work, the authors have highlighted many of the perceived benefits and pitfalls of XR technology in the field of engineering pedagogy and explored the effects of fidelity, cost and interactivity on student learning outcomes and virtual laboratory engagement (Bangert et al. 2023) in a flipped learning context. This practice paper aims to highlight ongoing work within the institution to enable better student engagement and efficient use of timetabled resources, whilst maintaining standards of learning attainment. The scope of this work has been based on the total replacement of a physical laboratory activity; the “Deflection of a Beam” lab. This activity is taught to over 150 undergraduate students from the Department of Civil, and General Engineering at the university. The 2020 meta-review previously mentioned (Radianti et al. 2020) suggested there was a lack of publications showing XR activities based on existing experiments, as is offered here.

1.1 Activity and Learning Objectives

The lab activity is based on the elastic beam theory. Students conduct a load test on a flexible elastic beam by hanging weights to it and record the maximum upward and downward deflections at each load increment. At peak load, students also record the cartesian coordinates of seven points along the beam. These data are used to plot the load-deflection curves and the deformed shape of the tested elastic beam. The data processing is assisted with the use of a spreadsheet template that is available to the students on the Blackboard VLE (Virtual Learning Environment).

The students are challenged to create their loading procedure design based on the setup limitations of the experiment, to experimentally interpret the concept of curvature and to justify any discrepancy with the theory.

Students are also expected to gain some laboratory skills, in this case, taking readings from various types of distance measuring devices and dealing with the associated errors and precision. For the students at this point in their studies, it could be the first time they have had to use any form of analogue dial gauge for displacement (see Fig 2).

1.2 The Physical Lab Apparatus

Fig 1 shows the experimental apparatus consisting of a simply supported steel beam, with a cantilever portion where the load is applied. Dial gauges 1 and 2 are used to measure the maximum deflection both within the supported span and in the cantilevered portion of the beam. Dial gauge 1 offers readings between 0-20 mm while dial gauge 2 is between 0-50 mm, both with graduations of 0.01 mm. A caliper and a micrometer are also made available to measure the specimen dimensions and a ruler to estimate the deflected shape of the beam at peak load.

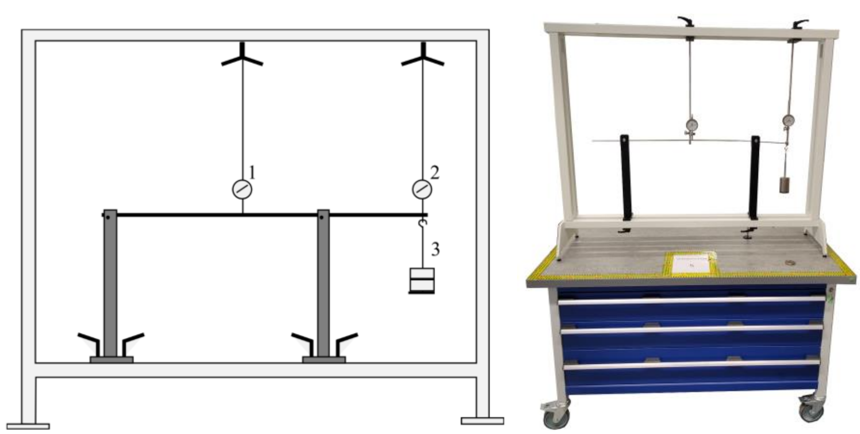

Fig. 1. Diagrammatic representation of experimental apparatus (Left) Photo (right).

1.3 Room for innovation

The existing format and structure of lab sessions have remained largely unchanged for the past decade, with only minor adjustments made over time. However, when compared to similar structural experiments conducted in the same laboratory, this particular session has consistently struggled with low student engagement and attendance rates. There's been speculation that this lack of enthusiasm may stem from student fatigue due to the repetitive nature of the experiments. Despite each experiment having different learning objectives, they all follow a familiar pattern of load-testing, data collection, and analysis, using similar equipment.

Recognizing this challenge, the authors opted to revamp the delivery of the activity while preserving its intended learning outcomes. This involved transitioning from the traditional lab format to a new approach with two distinct stages: 1) Substituting the original activity with a high-fidelity augmented reality/virtual reality (AR/VR) simulation. 2) Directly simulating real-world engineering examples related to the concept, rather than replicating the old experiment. This approach allows for the inclusion of virtual content that may not be feasible, safe, or cost-effective to implement on a large scale in a physical laboratory setting. The following outlines the initial phase (1) of this initiative and its impact on undergraduate engineering students.

2 METHODOLOGY

To realize a bespoke AR learning environment, a game engine was determined to be the optimal platform. This engine would offer the necessary functionalities: immersive visualizations, interactive features, and realistic physics simulations. Following a rigorous evaluation process, the free educational version of Unity 3D (version 2021.3.31f1) was chosen due to its extensive development tools and established compatibility with the selected hardware platform.

The chosen hardware platform consisted of Meta's Quest 3 headsets. These headsets offered a compelling cost-performance trade-off compared to alternative commercial VR systems. Furthermore, their integrated pass-through cameras and depth sensors were critical for facilitating the creation of realistic AR 3D overlays onto the user's physical environment. This technology is crucial for seamlessly blending virtual elements with the real world, a core requirement for an effective AR experience.

The simulation's geometric foundation mirrored the physical equipment's dimensions. These dimensions were meticulously captured and recreated within Solidworks, a 3D parametric CAD software. The resulting high-fidelity model was then exported for further processing in Blender, an open-source 3D modeling program. Within Blender, the 3D mesh underwent a process of optimization. This optimization aimed to minimize the file size while preserving the original geometric details of the model. This balancing act is essential for ensuring smooth performance within the AR experience. To achieve high-resolution measuring scales on the virtual gauges and rulers, a combination of procedural texture mapping and custom UV texture mapping techniques were employed. Procedural mapping allows for the efficient generation of textures based on mathematical algorithms, while custom UV mapping enables precise control over texture placement on the 3D model. Following this meticulous texturing process, the "texture-baked" 3D models were exported as glTF (Graphics Library Transmission Format) files (see Fig 2, right). This format facilitated seamless integration within the Unity game engine, paving the way for the development of the interactive AR learning environment.

Fig. 2. Photo of actual dial gauges (Left), Texture mapped glTF 3D model (Right).

The final component involved the utilization of several plugins within the Unity engine. These plugins, glTFast (4.8.3), Oculus XR Plugin (3.3.0), and XR Plugin Management (4.3.3), played a crucial role in managing file handling and facilitating interactions with the VR hardware. This integration ensured the proper communication between the software and hardware components, enabling the creation of a responsive and immersive AR learning experience.

Custom C# scripts were written to present an accurate deflection of the beam. The differential equations describing beam deflection were solved to give two equations for vertical deflection as a function of horizontal position on the beam for a given applied force: one valid in the region between the supports and one for the region of overhang. The mesh for the beam is divided into 100 sections. The vertices at each section are moved up or down according to the relevant equation, producing the impression of a smooth curve. Specific values at the locations of the dial gauges are similarly calculated for display with rotating hands (with values outside the measurement range of each dial gauge being clamped).

Parameters for beam dimensions and material constants are set within the unity editor (with the mesh automatically reflecting the given dimensions). The parameter for spacing between the pillars is inferred at runtime from the geometry of the scene, and the force parameter is updated as weights are added or removed by the user. A magnifying glass was implemented using a second camera attached to one eye of the XR rig with a narrower field of view than the default. This camera was rendered to the texture of a magnifying glass lens. This allowed a region of the scene to be viewed at a larger size and higher resolution than the natural scale and resolution of the headset without expensive ray tracing (Fig 3).

Fig. 3. In headset image of the magnifying glass effect on a gauge (Left) and ruler (Right).

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 flexible beam and mounting frame apparatus in the location where the activity is taking place (See Fig 4). Using the Oculus controllers or their hands, users can pick up any of the available weights (1, 5, 10 N) and place them on the weight hanger at the end of the beam to be tested. The users can also pick up the magnifying glass to help them see the measuring scales on the apparatus more clearly. Note, that the weights have physical interactions with the surroundings (gravity and collisions), whilst the magnifying glass interacts without collisions or gravity so that it can be placed in space without being held by the user.

The other interactive elements are the vertical measurement ruler, which can be moved on the x-axis along the length of the horizontal ruler, the rightmost support pillar for the beam, which can also be moved along the x-axis across the frame, and the hangers holding both measuring gauges, which can be similarly moved along the beam. Each of these axis-locked interactions has a restricted range of motion that matches those of the physical equipment itself. The interactive elements in this simulation are considered to be crucial not just for functionally mirroring the physical experiment, but also for increasing the rates of students' knowledge and skill acquisition in a virtual environment (Kyaw et al. 2019).

Fig. 4. 3D Unity scene view with the model of the experimental apparatus (left), In AR headset view of apparatus in the lab (center) and the real unit in the same lab (right).

2.1 Simulation Costings & Setup Estimates

As the physical activity has been run within the department for multiple years it was possible to get accurate figures on the amount of staff time required for setting up the teaching and therefore the costs. In addition, it was also possible to do the same for the development of the AR software and the setup of the VR hardware to facilitate the replacement lab activity. Table 2 shows this data with data based on staff time at ~£25/hr. Figures assume one continuous run of teaching, with classes of 40 students working in pairs. Total equipment cost scales in proportion to class size. Setup time scales in proportion to the number of runs of continuous teaching.

Table 2. Cost data for producing/running each form of the activity

Activity	Preparation of Materials (one-off)	Equipment cost per unit (GBP)	Setup and takedown time	Total
Physical Lab	N/A	Frame with beam deflection kits £3324 (x10 units required)	3.5 hours £87.5	£33,328
XR Lab	CAD/3D modeling: 20 hours. Unity development: 40 hours £1500	Quest 3 Headset with strap and gasket £580 (x20 units required)	4 hours £100	£13,200

2.2 Methods of assessment

Data on student engagement with the activity was recorded using a bespoke piece of attendance software designed and built with the department (Funnell 2020). The “Smiley Faces” application presents the students with a series of faces showing a range of 5 emotions from happy to sad on a touchscreen tablet, approximating a 5-point Likert scale. The students click on one of the faces when exiting the lab session to provide quantitative feedback on their experience. These data are aggregated numerically to produce a “satisfaction rating score”, see Table 3. In addition, the attendance rate of students was captured, see Table 4.

Table 3. Student Satisfaction Data

Session	Mean Rating (1-5)	Rating Std Dev	Respondents
Physical Lab 1 (2023)	3.9	1.36	8
Physical Lab 2 (2023)	5	0.00	4
XR Lab 1 (2024)	4.8	0.37	19

XR Lab 2 (2024)	4.9	0.34	23

Table 4. Student Attendance Data

Session	Students Expected	Students Attended	Attendance
Physical Lab 1 (2023)	31	23	74%
Physical Lab 2 (2023)	31	13	42%
XR Lab 1 (2024)	36	30	84%
XR Lab 2 (2024)	32	37	83%

2.3 Analysis of findings

The student satisfaction data (summarized in table 3) was combined into two cohorts: with and without XR. The null hypothesis was no increase in student satisfaction. Applying a Mann-Whitney U Test to the two groups , a z-score of -2.213 was produced. With one tail, this gave a p-value of 0.0134, which is greater than the 0.05 threshold to discard the null hypothesis. Thus we demonstrate a statistically significant increase in student satisfaction when presented with an XR lab experience. To what degree this is due to the quality of their learning experience versus the novelty value of using a VR headset is not known.

The attendance for the XR experience was much higher than in previous runs and is high compared to the average lab attendance (76%) and in particular the average attendance of 2024 CIV1000 students (67%), which was the cohort involved. The two 2023 physical labs, taken by GEE208 students, have an average attendance of 58%, which matches exactly the average lab attendance across the year for that cohort in 2023. To generate test statistics the cohorts were again grouped by presence of XR, and a two-sample proportion z-test was applied. The null hypothesis was no increase in attendance in the XR labs. A z-score of -2.93 was obtained, producing a p-value of 0.0034. This is smaller than the 0.05 threshold to discard the null hypothesis. Thus we show a statistically significant increase in attendance in the XR labs. Students were likely drawn to the lab because they knew it would involve a VR component, further suggesting this method of delivery is exciting to students.

The work by (Huang 2020) has shown that in other iVR studies, the “novelty effect” can be powerful in a science/engineering context. The students' motivation and engagement are initially higher, attenuating after multiple sessions. Novelty was not found to have a consistent impact on learning outcomes. As XR becomes more ubiquitous, it will be interesting to see to what extent our observed increase in engagement holds.

3 SUMMARY

This paper explores Augmented Reality (AR) as a way to revitalize a traditional engineering laboratory focused on elastic beam theory. The original lab suffered from low student engagement due to its repetitive nature. To address this, a high-fidelity AR simulation was developed, mirroring the physical apparatus and offering an immersive learning environment. Initial results show increased student satisfaction and attendance, suggesting AR's potential to enhance engineering education. While the long-term impact on learning outcomes needs further study, AR can prepare students for future careers using these technologies. Notably, for this specific lab setup, AR also presented a more cost-effective solution, although initial development required in-house expertise to create the model. Future work will focus on simulating real-world engineering examples in VR to further enhance learning and introduce scenarios impractical in a physical lab.

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