33rd Annual Conference of the Australasian Association for Engineering Education (AAEE 2022)
4 - 7 December 2022 – Sydney, NSW

The Integration of Augmented Reality Technologies in Engineering Curriculum

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ABSTRACT

CONTEXT

Over the past decade, the use of augmented reality has significantly increased over a wide range of applications. There are many good examples of Augmented Reality (AR) technology being used in the engineering, retail, and entertainment industries, however, the technology has not been widely adopted in education, and by university engineering departments. Although the number of studies discussing AR in engineering education has significantly increased over the past three years, most of the literature has focused on digitally enhancing the delivery of individual engineering principles or phenomena instead of a more general integration to the engineering curriculum.

PURPOSE OR GOAL

This study aims to investigate the effect of integrating augmented reality into an engineering education curriculum in higher education. Presently AR is utilised to complement the teaching of three engineering laboratories: the investigation of bending stress in a beam, flow over an aerofoil and a concentric tube heat exchanger. The current objectives are to develop integrated AR experiences and effective data collection techniques that will enable conclusions to be made on the educational impact of the technology.

APPROACH OR METHODOLOGY/METHODS

The AR experiences were developed and published using the commercial AR development platform Vuforia Studio/View. The digital assets were produced in collaboration with TecQuipment and all the tests were conducted using their laboratory equipment. The engineering experiments were replicated using numerical models obtained from commercial CFD and FEA packages. Questionnaires and quizzes were developed that will be used to test the technical knowledge of the participants and garnish feedback on their experience of using the AR technology.

ACTUAL AND ANTICIPATED OUTCOMES

The use of numerical FEA/ CFD with AR visually enhanced the overall laboratory experience. For example, the students will be able to see flow separation at stall for a wing section, the stress, strain and bending moment distribution across a beam and the temperature distribution across a heat exchanger. The students are expected to provide overall positive feedback for the use of the technology and suggest improvements to make the learning experiences better.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

With the current tools and technologies, the adoption of augmented reality in engineering education can improve the student learning experience. However, there are still several challenges to overcome to reach full adaptation of this technology to the engineering curriculum. Examples include: the availability of digital assets, the time and effort needed from educators to develop an AR experience and the long-term effect of the use of this technology on the educational outcome.

KEYWORDS

Augmented reality, Engineering Education

Introduction

XR, also known as extended reality, refers to a combination of real and virtual environments where interaction between humans and machines is established through computer-generated technology and compatible hardware (Doolani et al., 2020). Currently, the most common "X" representations are virtual reality (VR), augmented reality (AR), and mixed reality (MR). VR creates a digital environment where the user is wholly immersed in a virtual world. AR overlays (augments) digital content into the user's real-world environment. MR aims to blend both virtual and real-world environments where both coexist and interact with each other (Fast-Berglund, Gong, & Li, 2018). In engineering industry, the use of AR has been a key part of the industry 4.0 concept that focuses on advanced technologies in manufacturing systems and factories (Santi, Ceruti, Liverani, & Osti, 2021). The use of AR has been utilised in many ways by industry including visualising complex assemblies, facilitating training programmes, and developing maintenance programmes and manufacturing lines (Reljić, Milenković, Dudić, Šulc, & Bajči, 2021). In engineering education, the use of AR is significantly increasing compared to other STEM subjects (Mystakidis, Christopoulos, & Pellas, 2022). AR is being used as part of course material (i.e. (Solmaz & Van Gerven, 2021; Tsujita, Endo, & Yamamoto, 2017)), to visualise engineering laboratories (i.e. (Mejías Borrero & Andújar Márquez, 2012; Yazykova, Muzyleva, Gorlach, & Gorlach, 2020)), in collaborative projects (Schiffeler, Stehling, Haberstroh, & Isenhardt, 2019), for communication skills such as industry presentations (Topal & Sener, 2015), and to enhance students' spatial cognition (Bell et al., 2018; Dakeev, Pecen, Yildiz, & Luong, 2021). In the past ten years, several forms of AR hardware have been studied: handheld devices (HHDs) (i.e. (Dinis, 2017; Pan et al., 2017)), head mounted devices (HMDs) (i.e., (Guo, 2018; Guo & Kim, 2020), and special hardware kits (Louis & Lather, 2020; Theodossiou & Karakatsanis, 2018). In addition, AR can be integrated with several digital technologies such as gamification (Salman & Riley, 2016; Urbano, de Fátima Chouzal, & Restivo, 2020), machine learning (Alhalabi, Ghazal, Haneefa, Yousaf, & El-Baz, 2021), FEA (Matsutomo, Mitsufuji, Hiasa, & Noguchi, 2013), and CFD (Solmaz & Van Gerven, 2021) to produce more realistic, interactive, and scientifically credible AR experiences.

While there is some work underway to develop AR experiences for engineering education, little has been reported on the advantages of these experiences to support a wider curriculum. AR technologies have the potential to be engaging; however, a greater value is required if they are to become a permanent fixture in engineering courses. The AR experiences need to add to the curriculum content as well as the experience of the student. In STEM, Mystakidis et al. (Mystakidis et al., 2022) researched the most relevant topics where AR can be used, and the most frequent instructional methods to be used with AR in higher education. Still, a number of research questions may be posed: "Is AR most effectively utilised when new content is first introduced or to consolidate existing knowledge and skills?", "To what degree should AR experiences be scaffolded to enable students to address learning objectives?", "Is the knowledge gained from the use of AR easily translated to other contexts and tasks or are supporting activities required to achieve this?", and "What is the role of formative assessment, group work, and discussion before, after, and during AR experiences?".

The availability of AR experiences continues to be the principal barrier to the testing and adoption of AR technology by universities. The equipment and software needed to develop realistic and high-quality experiences is often expensive and requires expertise. However, it is essential to develop affordable experiences to encourage educationalists to test and adopt the technology. An AR platform that allows lecturers to develop their own experiences for a low cost may enable an accelerated uptake of the technology. It would also facilitate students to participate in the development of the educational AR experiences (Bourguet et al., 2020; Shen et al., 2019). For K-12 education Mystakidis et al. (Mystakidis, Fragkaki, & Filippousis, 2021) developed an online professional development program for teachers training, which included AR and VR modules. Training higher education educators in developing educational AR content can significantly ease the integration of the technology into the engineering curriculum (Sugandi & Wena, 2022).

Figure 1a: Stress in a beam **Figure 1b: Wind tunnel** **Figure 1c: heat exchanger**

Figure 1. Experiment devices chosen for digital enhancements.

Takrouri et al. (Takrouri, Causton, & Simpson, 2022) reviewed the use of augmented reality in engineering education in the past 10 years. In terms of AR development, most of the reported literature used mobile application development and 3D modelling tools (such as Unity, Vuforia, Arkit, or ARcore). These tools are easy to access, offer plenty of educational material, and are accessible to end users due to their compatibility with most common operating systems including HHDs and HMDs. It should be noted that none of the reviewed papers mentioned commercialising the AR tools developed or using them outside the context of academic research. For AR consumption, although third-party applications are a way to access AR experiences and there are several commercially available applications on the Apple App Store and Google Play Store for AR, there are no reports in the literature that these applications have been used in engineering education. This work presents engineering education augmented reality AR experiences developed using a commercial AR development and consumption platform Vuforia which is also widely used in the industry for instructional and training purposes.

Aim and objectives

This study aims to investigate the effect of integrating augmented reality into an engineering education curriculum in higher education. At this stage the use of AR is utilised to teach three engineering lab experiments: bending stress in a beam, flow over a symmetrical NACA0012 aerofoil and a concentric tube heat exchanger. The proposed AR experiences extends the usability of the experiment hardware, gives students a chance to visually understand engineering phenomena like wing stall, increase motivation, entertainment, and interactivity within the lab equipment, visually enhance the data produced from the lab equipment and provide an insight to the effect of using AR on the students beyond the "WOW factor" already associated with the metaverse related technologies but instead form a pedagogical point of view.

Educational added value

For the bending stress in a beam shown in Figure 1a, there are several educational objectives; to understand load and strain gauge relationship for a beam subjected to load, to calculate the maximum stress on the beam and to calculate the position of the neutral axis, to compare the results to theory, and lastly to visualise reaction forces, stress, strain and bending moment distribution across the beam. The experiment hardware allows the students to read and record values of strain gauges after applying loads, calculate corresponding stress values from strain gauge readings, calculate the position of the neutral access and compare the results to theoretical calculations. The AR experience will allow the students to additionally calculate and visualise the strain, stress and bending moment distributions across the beam in addition to the shear-moment diagrams. Additionally, it will allow the lecturer to introduce real world applications related to the presented experiments (for this case an inverted T-beam).

For the wind tunnel laboratory shown in Figure 1b, the learning objectives are to measure lift, drag and pitching moment at different incidence angles, to calculate lift, drag, pitching moment coefficients and lift to drag ratios, to understand an aerofoil's optimal performance conditions like maximum lift and maximum lift to drag ratio and to introduce the concepts of wing stall and flow separation. During the lab, the students are expected to read and record values for lift, drag pitching moment and their corresponding coefficients at different angles of attack, and determine pressure the distribution along the aerofoil section. Using the AR tool will allow the students to digitally visualise the flow field at each angle of attack and visually compare the change in flow before and after stall.

For the concentric tube heat exchanger shown in Figure 1c, the main learning objective is to understand how heat exchangers work and the difference between heat exchanger units, the laboratory heat exchanger unit allows the students to read temperature change across the heat exchanger for parallel and counter configurations at different flow rates using thermocouples. With AR, the students will be able to visualise in 2D the temperature distribution in addition to the 3D flow across the heat exchanger.

Methodology

There are multiple stages in the development of educational AR experiences. The first stage is to define the expected added value the educational digital product as discussed in the previous section. The second stage is the creation of the digital material. For the presented work, the laboratory experiments were numerically simulated to replicate the physical experiments using ANSYS CFD and Mechanical. The use of commercial engineering software gives scientific credibility to the developed AR experiences as the built-in numerical models have been validated against experimental data. The simulations were further validated against data from the laboratory equipment being modelled. The third stage is to post-process the simulations, so the output data is compatible with the AR development software of choice. This may include 3D file format conversions, post-processing of the simulation data using software such as TecPlot or ParaView, and 3D modelling using Blender, and photo or video editing. Once the digital assets library is ready, the final stage is to build the AR experience. In this case the AR platform of choice is Vuforia studio. In Studio, the users can use their 3D CAD files, images, or area scans as model targets and augment their digital assets in different forms (i.e. 3D models, labels, images, video and pdf files). The digital assets animation can be done using Java scripting.

Once the AR experiences are developed, they are published to the cloud and users can access them by scanning a QR code dedicated to the experiments. The experiences can be viewed either using HHDs including tablets and phones or HMDs such as the Microsoft HoloLense. It should be noted that the control and interaction with the digital assets in the AR development process is different for 2D HHDs and 3D HMDs. For 2D, developers can use sliders, 2D buttons and gif files whereas for HMDs experiences navigation is limited to the use of 3D buttons only.

Results and Discussion

Figure 2 shows some examples of the augmentations that can be done using an AR digital experience. They include the moment distribution around an inverted T beam (2a), wing section flow fields in addition to lift, drag, moment and lift to drag ratio plots (2b), and the temperature distribution across a heat exchanger (2c).

One important aspect to take into consideration for a wider adaptation for AR technology in engineering education is the computational time and resources needed to develop the experiences (Chlebusch, Köhler, & Stechert, 2020). All the presented AR experiences in this work were developed using a PC (Table 1) without any access to High Performance Computing (HPC) machines. The computational time and problem size for all simulations are shown in Table. 2. The same PC was also used to render all the AR graphics and to develop and debug the AR experiences.

A comparison of the results from the performed simulations and the experimental data is shown in Figure 3. Overall, there is good agreement between the numerical and experimental data, however, for the wind tunnel experiment, there are some small discrepancies. The small discrepancies could be attributed to small deformations in the wind tunnel flow straightener, the mounting pole used to hold the wing section in place or inaccuracies in the wind tunnel balance. There is also an error associated with capturing flow separation using RANS turbulence models.

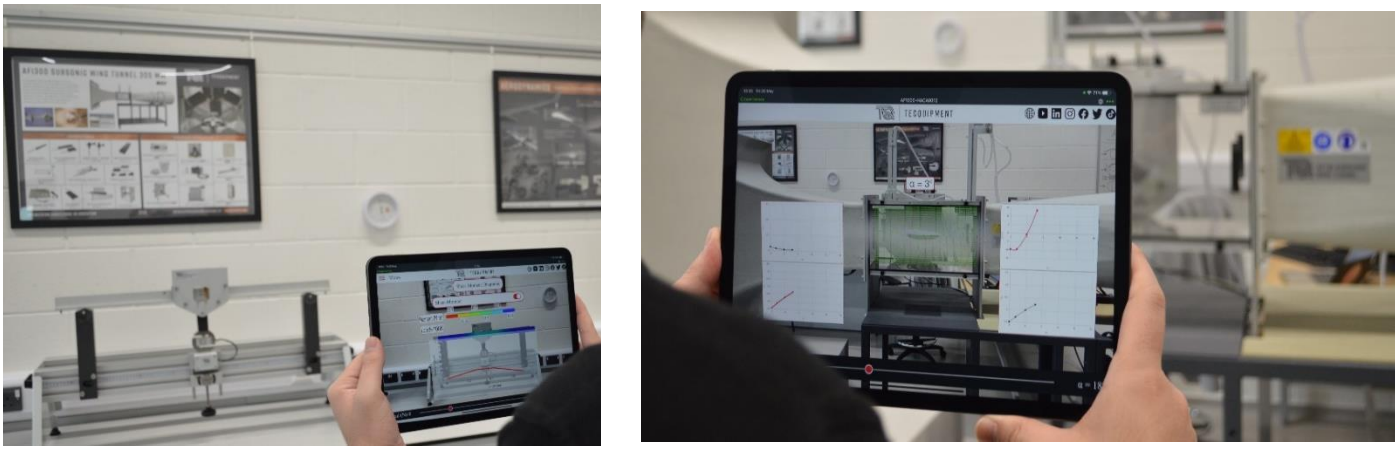


Figure 2a: Beam moment distribution. **Figure 2b: Wind tunnel flow field.**

Figure 2c: Heat exchanger temperature distribution.

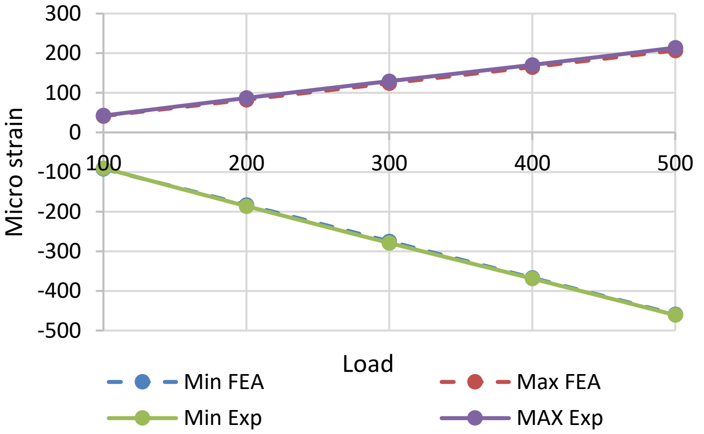
Figure 2: AR augmentations examples.

Table 1: Pc specification used to develop the AR experiences and experiments numerical models.

Processor	Intel Core i7-9700K 8 core 3.6GHz
Memory	16 GB RAM
Storage	1 TB SSD
Graphics	GEFORCE RTX 2060 6GB GDDR6
Operating system	Windows 10

Table 2: Problem specifications for experiment numerical models.

Experiment	CFD/ FEA number of nodes	Computational time for one scenario
Bending stress in a beam	1D Ansys beam model <150 nodes	< 1 min
Wind tunnel NACA0012 (pre stall)	860186	6 mins
Concentric heat exchanger	948591	17 mins



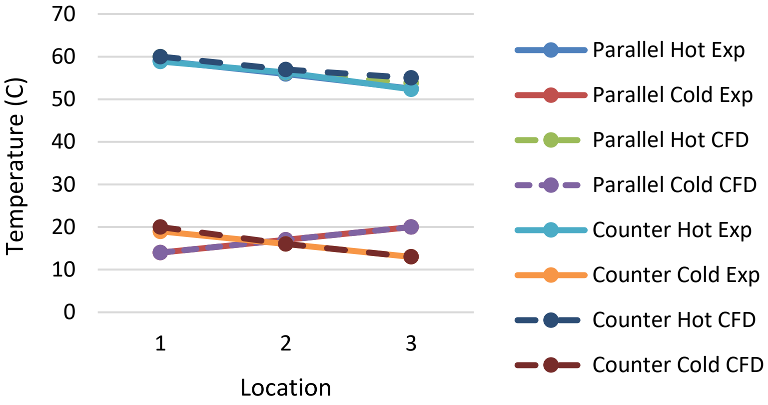


Figure 3a: Maximum and minimum strain. **Figure 3b: Heat distribution for heat exchanger at 3 L/min.**

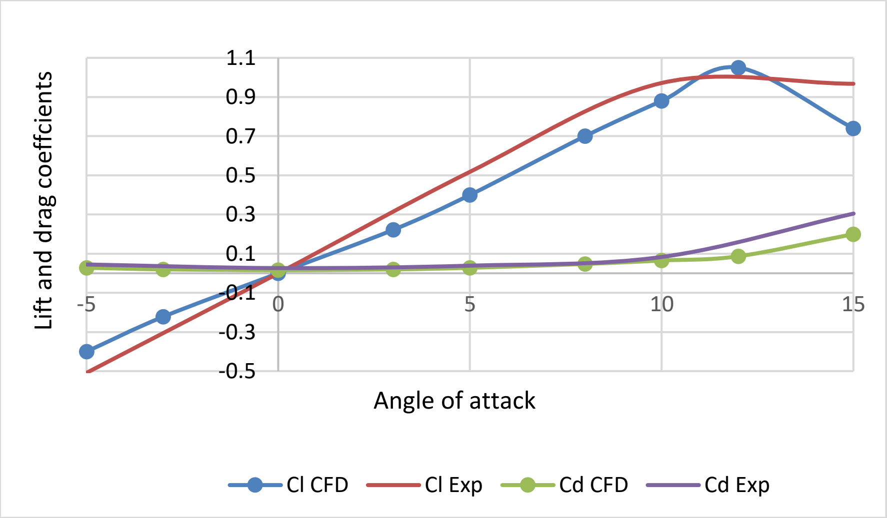


Figure 3c: NACA0012 lift and drag coefficients.

Figure 3: Numerical models validation compared to experiments.

One advantage of using commercial AR platforms rather than in-house developed mobile applications, especially as many engineering educationalists are not familiar with developing mobile applications (Mystakidis, Fragkaki, & Filippousis, 2021; Nesterov, Kholodilin, Shishkov, & Vanin, 2017), is the ease of distribution and debugging. This can lead to faster integration of the technology into an engineering curriculum as lecturers only have to focus on the developed material rather than developing the application. Furthermore, the developed experiences are compatible with a wide range of file formats and smart devices. The plug and play approach provided by some commercial tools translates into less setup and tutorial time during lectures (Borgen, Ropp, & Weldon, 2021). It also allows researchers to focus on the quality of the content provided within the AR application rather than collecting feedback on the technical aspects of the AR software such as speed, ease of use, security and coding bugs. Additionally, commercial platforms provide the opportunity to integrate other technologies into AR experiences such as digital twinning (Aheleroff, Xu, Zhong, & Lu, 2021).

To collect the students' feedback preliminary and experience questionnaires in addition to technical quizzes are used (Takrouri et al., 2022). The students are asked to complete the questionnaires and the quizzes after completing each of the lab experiments and their performance is compared to a control group who didn't use AR during the lab. After three months, the students (including the control group) will be asked to complete a technical quiz to determine if using the AR had an impact on their understanding and their ability to retain the information.

Future work – AR trial

The next step of this work is to run a long-term study to assess the pedagogical value for the use of AR in engineering education. Previous literature has reported positive overall feedback from students after using an AR experience. Part of this feedback might be due to the "WOW factor" associated with the use of AR as part of the metaverse technologies. However, limited research has reported the long-term effect on education of using AR experiences. To assess the long-term educational impact of using AR technology, trials are underway where the users are firstly asked their opinion on the technology and secondly asked to complete two knowledge quizzes, one directly after they use the AR experience and then a second one three months later. The knowledge quizzes are taken by one group of students who do the laboratory with the AR experience and a second control group of students who undertake the same laboratory but without the AR experience.

Conclusions

With the current tools and technologies, the integration of augmented reality into engineering education can potentially enrich the students' learning experience and extend the laboratories hardware capabilities. However, there are still several challenges to overcome to reach full adaptation of this technology to the engineering curriculum. Examples include: the availability of digital assets, the time and effort needed from educators to develop an AR experience and the long-term effect of the use of this technology on the educational outcome.

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Acknowledgements

This research was funded by Innovate UK and TecQuipment for engineering education grant number 12276. Knowledge Transfer Partnerships (KTPs) aim to help businesses improve their competitiveness and productivity through the better use of knowledge, technology, and skills within the UK knowledge base. The authors would also like to thank LEAP Australia for all their help and support.

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