Immersive Visualisation – seeing the engineering problem in surround vision.

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Introduction

USC has invested in a suite of visualisation technologies to meet the advancing demands of future-focussed technological enhanced learning (TEL) and to increase engagement with STEM subjects. Tertiary education literature highlights the need to equip students generally, and engineering students in particular, with the skills that make them ready to function in the engineering practice. This includes the development of critical thinking skills, and abilities to contextualise and apply knowledge to different problems (Breslow, 2015; Kolmos & Holgard, 2019; Boles *et al.* 2010). This paper reports on the use of visualisation to support student engagement and their development of spatial critical thinking and problem-solving skills.

Three dimensional (3D) spatial skills are key for successful engineers (Akasah & Alias, 2010; Carbonell *et. al.* 2011; Sorby, 2007) and are very difficult to teach (Akasah & Alias, 2010 ; Ha & Fang, 2015). Visualisation has been an effective method in presenting engineering problems (Alias, *et. al.,* 2002) and with improvements in computing, visualisation methods are increasing in complexity and are now available in different forms. The use of Web-based augmented reality that combines computer-generated information with real-world is known to be used to carry out difficult procedures that enhanced understandings in the learning environment (Liarokapis*,et al,* 2004). This paper proposes that a 3D immersive visualisation environment can provide an opportunity to develop spatial skills, as it has been demonstrated by Akasah & Alias (2010), by taking a 'whole-to-parts' approach, in teaching engineering design.

Aligned with this approach, a clear theme from previous Australian University studies is that "students need to see theory in the context of applications" and students overwhelmingly favour the visual over verbal instruction (Boles, *et. al.*, 2010). This finding highlights the potential lack of alignment between the traditional lecturing style of engineering education and the dominant learning styles of the student cohort (Felder & Brent, 2005) and supports this exploration in the use of visualisation. The use of virtual reality therefore, provides an additional edge to learning style and it is proposed (Kolari & Savander-Ranne, 2004) that it is an effective means of addressing diversity in students learning styles.

Using visualisation in engineering education has been a well-recognised method of improving engagement (e.g. Abulrub, et. al. 2011 and Liarokapis, et. al. 2004). It is known to increase perception and the understanding of the problem. In addition, it has been used to provide a remote laboratory experience to distantly located students (Fabregas, *et. al.* 2011). The use of the present technology of CAVE, however, brings a unique dimension to visualisation of the engineering problem in a surround situation. The system is capable of interacting with differentiated media that allows the interlace of 3D, pictorial or graphical and 2D pictorial and video. The immersive experience is enhanced by 320^{o} curvature of the screens that bring a surround effect. The visualisation room is designed for an audience of 20 which allows teaching in a tutorial style presentation where a group of students can have a common viewing experience after which they can break into smaller groups for discussion. Visualisation has been identified as a natural means of promoting student discussions and engagement with one another (Kolari & Savander-Ranne, 2004).

In restructuring the courses that were chosen to be delivered in the visualisation facilities, consideration was given to how the immersive environment could be used to enhance students' critical thinking skills, collaboration and problem-solving. Numerous studies (Kolmos & Holgaard, 2019; Prosser & Trigwell, 1999a, 1999b) indicate that student perception of a situation and the importance of the skills to be developed play a very important role in their engagement with the task and their ability to solve a problem. Our work here is to address how the perception of situations enabled by the content presented in an immersive environment would increase students understanding of engineering problems. We chose two cases, one a design problem of humanitarian engineering, and the other focussed on presenting the highly theoretical content of the atomic universe in engineering materials. In both cases, the visualisation enabled access to an environment unreachable by other means and placed students at the centre of the learning environment.

Case Study 1: Visualisation in *Introduction to Design*

The first case study was in an engineering design course for first-year students. The main learning outcome of this course is to introduce students to the concept of a "whole system" approach to solving problems. In order to achieve this learning outcome, the assessment tasks were designed so that students would apply the basics concepts of system design to provide solutions for a product development and a humanitarian design problem.

It was fairly simple to offer a clear brief of the expectations for the product design problem, particularly to identify the product application and its intended use. However, the humanitarian design problems required a significant amount of detailed explanation to ensure students could grasp the issues involved. We use the annual, Engineers Without Border (EWB) design challenge as the basis of the assessment which already comes with a well-detailed design brief and an outline. The challenge we faced with this type of brief was the setting and issues involved are foreign to a typical Australian student. It was difficult for them to build up images in their minds of the situations being described, even with the few pictures that accompany the EWB project documents. We felt that this lack of visual perception and understanding of the wider environment may limit the extent of their engagement. The obvious and impractical way to address the student's limited situational awareness would be to take students to the site under consideration.

This was a perfect reason to use the visualisation facility. The visualisation content was developed for Bambui Cameroon, West Africa, the region chosen for the 2015 EWB design challenge using freely available satellite data. Through this, it was possible for students to experience a fly-through of the Bambui region, and to gain a general understanding of lifestyle, quality, and nature of the housing, town planning and other issues critical to the design challenge.

Figure 1 gives the picture of the starting point on the Digital Bambui. Based on the information from the EWB brief, detailed, enhanced imaginative compositional views of specific scenes were developed:

- Open Market,
- School and school hygiene
- Farm and food processing
- Public toilet,
- Housing,
- Outdoor and indoor kitchen,
- Natural water source, and
- Refuse dump.

Each of the composed scenes was developed to highlight issues relating to the different design considerations of water supply, sanitation and hygiene, energy, food processing and storage, transport, and urban planning. A front-page menu was developed to support navigation to the highlighted locations. The developed scenes present in a 3D wrap-around space, which gives the student an immersive experience.

Fig. 1: Image of Digital Bambui village used for Humanitarian design problem in the CAVE.

As the EWB challenge site changes every year it was important to focus on the relevant issues in developing world contexts such as water supply, hygiene, and sanitation, waste disposal, energy, food production, and transportation. Though the location changes every year for EWB design challenge, the issues are constant. The digital Bambui TEL learning artefact in the CAVE environment, therefore, vividly presents these issues and enables us to use this model as a basis to practice for other EWB challenges.

Case Study 2: Visualisation in *Engineering materials*

The engineering materials course is an introductory level course in our engineering program. A key learning objective is to introduce students to the properties of materials and for them to apply this knowledge in choosing different materials for various engineering applications. At USC, we took a science-based approach in attempt to reach these learning goals. This require that an engineering material is conceptualised from atomic scale. Taking this approach requires that students must be able to perceive and understand atomic build up that leads to measurable engineering properties. The challenge we faced was that most students do not have the necessary chemistry background and those that have could not apply the concepts to current situation. They mostly found the concept of universe of atoms in orderly arrangement too difficult. We decided to address this learning issue with a core a threshold concept (Baillie, et. al., 2013; Baillie & Male, 2019). We felt once understood by visualisation of different atomic arrangements, they would experience fundamental learning transformation that would permanently shift their understanding. Initially, we used the traditional physical models where we represented unit cells with physical MODELS of different crystal structure. While students enjoyed building models, the scale of the problem was too large to adequately represent the situation in real engineering materials with a few model atoms. The physical model approach was time-consuming, and impractical to demonstrate in a large class. From student feedback, many loose interests as they were unable to picture the models in a real engineering material. In any case, using a unit cell model outside the whole universe of atomic environment amounts to isolation of problem from its it's surrounding and students found it difficult to conceptualise how the separated model interacts and fits into the environment in a real engineering material.

Once again, this seemed like a perfect opportunity to use the 3-D immersive environment. The availability of a facility like the CAVE enabled us to come up with the idea of presenting the atomic universe of engineering materials in an immersive environment. The content was developed such that students are able to drill down from a normal tool to microstructure and to atomic levels. We introduced the 3D immersive model in the first semester of this year as an additional non- binding supplementary activity. The use of 3D visualisation allowed us to step down through the different scales of interrelationships of structure from the macro down to the micro and nanoscales. For instance, student have the ability to see relationships of different atomic arrangements and the density of materials. Figure 2 shows some common atomic arrangements that students were able to interact with. Students enjoyed this interactive learning tool so much that some came twice! Students were interviewed about their experience.

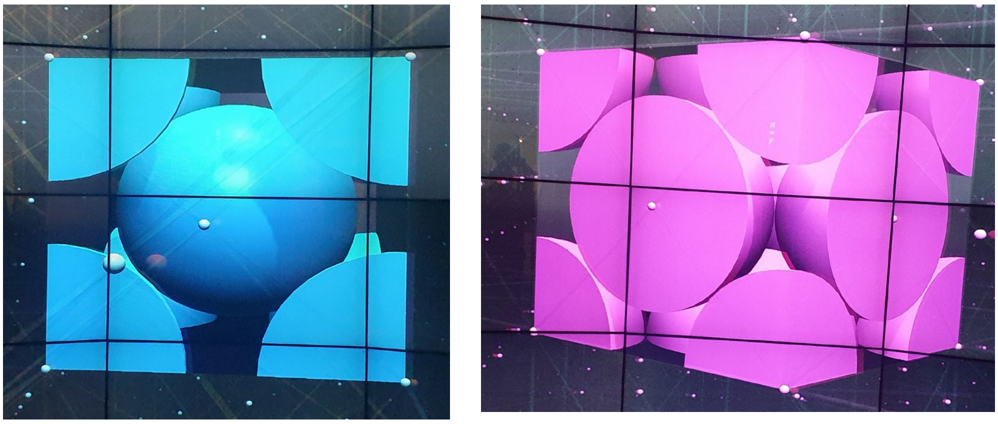


Figure. 2: Images of atomic arrangements representation in the CAVE.

Results and discussion

The use of technology-enhanced learning (TEL) in higher education is now an embedded and expected practice. Poirier & Fieldman (2012) has emphasized its important role in enhancing the quality of teaching. Our expectation was that the immersive visualization would enable a greater depth of understanding of engineering problems and would increase engagement. It was also proposed (Baillie & Male, 2019) that engagement with an immersive learning tool would support the learning of a threshold concept that could be an expression of irreversible learning. We observed that in these two case studies, students' understanding, and performance improved with the introduction of visualisation.

Many students expressed that technology helped their understanding of tasks. A few made particular mention of their excitement with the immersive environment. Our anecdotal observations found that students were looking forward to being engaged with the immersive environment and 3D technology. It is hard to judge if their expectations were met, but the positive feedback suggests their interests were sparked.

At the outset of this project for the introduction to design course, we set up post-course surveys that ran for three years. A representative of response is shown in Figure 3, where it demonstrates that nearly 90% of students had a positive view of the effect of this technology on their learning and more than 90% agreed (Figure 4) that the learning experience helped them to achieve the course learning outcomes. A student responded as:

"Very good course. My favourite piece was viewing the EWB problem in the CAVE"

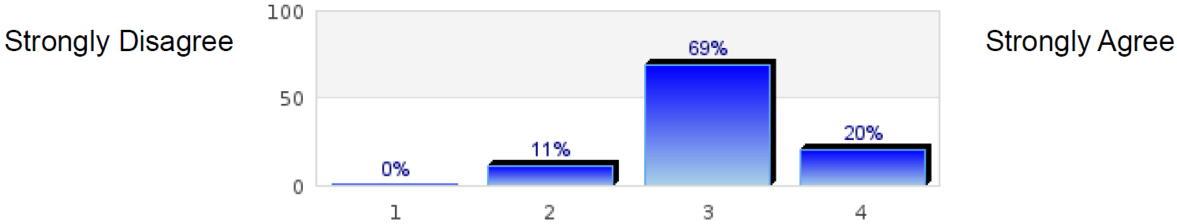
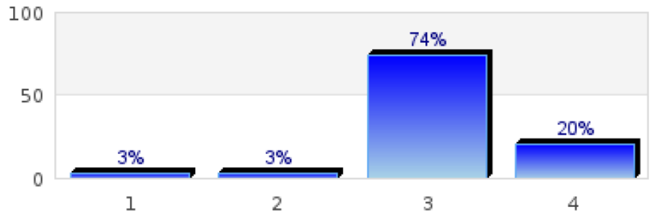


Figure. 3: Student's view of the effect of Technology on the Introduction to Design course. (1, Strongly disagreed, 4 Strongly agreed).

Strongly Disagree



Strongly Agree

Figure. 4: Student's view of the effect of overall experience in achieving the learning outcome Introduction to Design course (1, Strongly disagreed, 4 Strongly agreed).

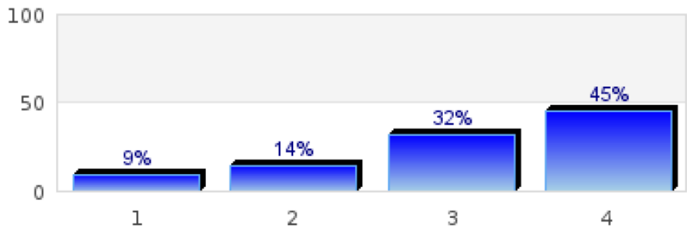
In the Engineering Materials course, 87% of the students expressed that the learning experience helped them to achieve their learning goals which were very confirming as this was a difficult threshold concept. The end of course survey indicated that nearly 80% of the student agreed that their visualisation experience helped them to achieve their learning goal.

At the end of one-semester survey, we were happy to read:

> *"…the presentation in the cave was very successful and helped me to comprehend the material in a fun and creative way!"*

It provided an engaging experience for the student to explore the atomic worlds and provide the opportunity to travel from atomic locations for different types of possible arrangements. The ability to zoom in and explore atomic arrangements in different types of the crystalline structure made it possible to apply simple geometrical concepts to solve problems that hitherto were difficult to express on a 2D paper space. In comparison to previous years' assessments, students exhibited a better understanding of crystal structures suggesting many more would have gone over capability threshold limit to gain the level of irreversible learning as expressed by (Baillie, C. *et. al.* 2013).

Strongly Disagree



Strongly Agree

Figure. 5: Student's view of how their experience help to achieve learning goal in Engineering Materials (1, Strongly disagreed, 4 Strongly agreed).

Implication for future

The CAVE experience of visualisation has confirmed the role visualisation could play in increasing engagement of students for situations when it is difficult to bring the situational problem to the class room environment. The outcome here is consistent with the literature view (Abulrub, *et. al.*, 2011; Akasah & Alias, 2010; Fabregas, *et.al.* 2011; Liarokapis, *et. al.* 2004) of the positive role of visualisation in enhancing engineering education. The engagement from visualisation are capable of increasing students ability to perceive and understand complex engineering problems. Educators therefore, have long understood the usefulness of visualisation methods in deciphering complex engineering problems and have invested in computer software in providing various visualisation experiences of modelling and virtual reality. In the present study, the visualisation experience in the CAVE provides a unique experience of a classroom-like environment of grouped viewing. The cost of investments in such immersive visualisation technology is expected to remain a challenge for adopting such technologies into the engineering education. Now, at USC, other disciplines; nursing and health education are also making effective use of the visualisation and immersive experience the CAVE provides. As the cost spreads across disciplines and as the effectiveness in promoting engagement get recognised, we would expect that investments in immersive visualisation facilities can be justified and could be adopted as an essential facility in the tertiary education industry. It is a demonstrated tool for viewing large scale engineering projects for future developments to showcase infrastructures before they are built. Currently, we are promoting it for commercial use, and it is hoped if it could be offered as a service to corporate and government establishments, income generated may make it viable as an institutional asset.

Conclusions

These two case studies highlight how carefully constructed and purpose-built immersive learning objects supported positive student engagement to learning about an unfamiliar engineering context and a complex threshold concept. The positive comments and high ratings from students on the two courses suggest that this new technology is an effective tool in presenting engineering information. In the case of humanitarian design, the immersive visualisation of 3D developed specifically Bambui location was an effective tool in providing a genuine perspective of the issues in water supply, sanitation, and energy.

The visualisation artefact for the theory-based materials enabled students to explore and imagine the microscopic space of the atomic universe in an engineering material. We received very good feedback on the effectiveness of this simulation to help students understand the concepts relating to the arrangement of atoms and the concept of the unit cell. More than 80% of students agreed that visualisation helped them to understand the atomic universe in engineering materials and had helped them achieve the learning goals in this course. Overall, these two case studies demonstrate that the use of immersive visualisation can be an effective tool to engage students in learning both contextual and conceptual information.

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