Evaluation and integration of simulation technologies for teaching and learning physics

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Abstract

The University of the Sunshine Coast (USC) is the first tertiary institution to utilise the CAVE2™ for teaching and learning and houses a Collaboration Studio containing a large, high-resolution display wall with 2D and 3D capabilities. The aim of this project was to investigate the impact that simulation technologies and visualisation facilities had on learning in three Physics-related Engineering courses at USC. The findings demonstrate that teaching with these facilities requires careful curriculum design in order to facilitate a meaningful and deep learning experience. Key influences on learning were investigated through a phenomenological study and were informed through student evaluations and face-to-face targeted interviews with students enrolled in focus courses. The instrumental factors in the enhancement of learning include the lecturer’s pedagogical strategies, usage of the facilities, the student’s learning preference, and the quality of the visualisation artefact. This paper proposes recommendations for their integration into the Engineering curriculum to create a more meaningful student learning experience.

Keywords: visualisation, learning and teaching, physics, engineering, CAVE2
Visualisation

Notions of visualisation in education have progressively included modern forms of innovative technologies. In early educational institutions, visualisation incorporated the picture use to enhance the processing of concepts and was regarded as a non-universal practice (Presmeg, 1986). Modern notions of visualisation incorporate the process of meaningful conceptions through translation between representations in mediums such as virtual reality environments, high-resolution display walls, and hybrid reality environments (Yang, 2014).

Virtual reality environments are used in learning and teaching applications to enhance student understanding (Nguyen & Khoo, 2009). Virtual reality environments are often based on the real world and facilitate the visualisation of 3D data (Huang, Rauch, & Liaw, 2010). Huang et al. (2010) defines a virtual reality framework for the integration of virtual reality technologies in learning known as I³ – immersion, interaction, and imagination (Burdea & Coiffet, 2003). Immersion refers to the mental aspects of a user becoming deeply involved in a virtual world further to the physical aspects of a user taking control and navigating their way through the virtual world (Huang et al., 2010). Interaction refers to the virtual world possessing the capability to instantaneously respond to user gestures and provide stimulation to users sensorial channels such as visual and auditory elements (Huang et al., 2010). Finally, imagination refers to the ability of virtual worlds to trigger creativity within users and allows them to participate in higher-order problem-solving exercises (Huang et al., 2010).

High-resolution display walls have played an integral role in visualisation, particularly in research. Modern research frequently involves the exploration of scientific phenomena
and the capabilities of a display wall allow for the interpretation of large datasets for collaborative analysis (Febretti et al., 2014).

Hybrid reality environments seek to combine the best aspects of virtual reality environments and high-resolution large display walls, to facilitate an immersive experience for participants. One particular hybrid reality environment is the CAVE2™, which has been instrumental for research and has allowed researchers to explore 3D spatial datasets, such as molecules, astrophysical phenomena, and geoscience datasets (Febretti et al., 2014; Febretti et al., 2013). At the time of this project, only four CAVE2™ facilities in the world exist and the University of the Sunshine Coast (USC) is the only tertiary institution to use the facility for learning and teaching purposes.

**Learning and Teaching: Engineering and Physics**

In Engineering and Physics-related disciplines, a need exists to integrate experiential modes of learning with traditional classroom instruction (Sanchez, Ruddell, Schiesser, & Merwade, 2016). Experiential learning refers to the development of knowledge through experience (Kolb & Kolb, 2005). This learning mode has major benefits to students as deeper understanding is more likely to occur when students are actively engaged (Sanchez et al., 2016). Many students within Engineering and Physics have expressed concern with traditional lecture-based and teacher-centred methods of instruction which fix normative goals for students in contrast to allowing students to take responsibility for their learning (Sanchez et al., 2016). Furthermore to creating a student-centred learning environment, increasing student motivation through authentic and problem-based activities, furthermore support the development of deeper conceptual understanding (Antonio, Lima, Alves, Silva, & Simão, 2016; Sanchez et al., 2016).
Visualisation in Physics-related Courses at USC

The CAVE2™ provides numerous educational opportunities, however there is little literature present on its integration in learning and teaching.

USC also houses a Collaboration Studio, which at its focal point is a large, high-resolution display wall. In this room there are a number of tables to facilitate group work and collaboration. By integrating the visualisation facilities into the USC Engineering curriculum, this supports the integration of authentic modes of learning to facilitate deeper understanding and motivation (Sanchez et al., 2016; Velazquez-Marcano, Williamson, Ashkenazi, Tasker, & Williamson, 2004).

This project will focus on the CAVE2™ and Collaboration Studio, based on the following questions:

1. What impacts do simulation technologies have on learning for students in Physics-related courses?
2. How do we effectively use the visualisation facilities to enhance learning?

Methodology

A phenomenological project was designed for the collection of data based on emerging themes of individual students’ experiences to determine a framework for the integration of simulation technologies. Three data collection methods were implemented in order to perform a thematic analysis on individual students’ responses. These methods include:

- Focus course observations
- Face-to-face and online surveys
- Face-to-face targeted interviews
The focus courses for this study were first and second year engineering courses which utilised the new visualisation facilities as part of their learning sequence. The students who participated in the data collection were those whom attended their course A, B, or C lecture in either week 12 or 13 of semester one, 2016, or participated in the face-to-face targeted interviews conducted in week 13.

**Observations of Focus Courses**

Throughout semester one, 2016, observations of lectures in course A, B, and C, were conducted. This was undertaken to link individual student experiences with the teaching dynamics in the classroom. The following observations took place:

- Course A was observed twice – once during the use of an artefact in the Collaboration Studio, and once more in week 12;
- Course B was observed for an hour each week throughout the semester; and
- Course C was observed twice – once during the use of an artefact in the CAVE2™ and once more in week 12.

**Face-to-face and online surveys**

In collaboration with the USC division, Centre for Support and Advancement of Learning and Teaching (C-SALT), a survey was developed which acted as a data collection tool for this project. Table 1 lists the series of questions which students completed. Students had the option of completing the survey in hard-copy format or online through SurveyMonkey. All students in course A and course C completed hardcopies and a majority of students in course B completed the survey through SurveyMonkey.
Table 1: Survey questions

1. Age
2. Gender
3. Modified Likert scale evaluation on meeting focus course Learning Outcomes
4. What was the most difficult content covered in the course? (open-ended)
5. How did the use of technology in the course assist in your learning? (open-ended)
6. Modified Likert scale evaluation on whether the lecture and tutorial material helped learning
7. Modified Likert scale evaluation on whether the technologies helped learning
8. Modified Likert scale evaluation on whether tutorial/labs helped learning
9. What was your favourite learning activity in the course? (open-ended)

Two additional questions were asked following the conclusion of the survey. These questions varied slightly in each focus course due to the nature of each course. Table 2 lists the additional questions asked.

Table 2: Additional questions asked in each focus course

<table>
<thead>
<tr>
<th>Course</th>
<th>Additional Questions</th>
</tr>
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</table>
| A      | 1. How did the use of the Collaboration Studio affect your learning?  
        | 2. Would you have achieved the same level of understanding in this course, if this class did not use visualisation technologies? (i.e. collaboration studio and 3D simulations) |
| B      | 1. How did the use of the Collaboration Studio affect your learning?  
        | 2. Do you think you would have achieved the same level of understanding if this class was held in a traditional lecture/tutorial room? |
| C      | 1. How did the use of the CAVE2™ affect your learning?  
        | 2. Would you have achieved the same level of understanding in this course, if this class did not use visualisation technologies? |

C-SALT also provided data from a similar survey prior to the introduction of the visualisation facilities at USC for comparative purposes. It should also be noted that a
“modified” Likert scale refers to a standard Likert scale (strongly agree, agree, neutral, disagree, and strongly disagree) with the “neutral” option removed. The neutral option was removed as it was felt that it did not give a sufficient understanding of how the students felt in relation to the respective question.

**Face-to-face targeted interviews**

During the delivery of the face-to-face and online surveys, students in each course were asked to volunteer to participate in a focus group to facilitate further in-depth responses. A one-hour timeslot was scheduled in week 13 semester one, 2016, for the targeted interviews. Table 3 lists the series of main questions asked of the participants.

**Table 3: Main themes of targeted interview questions**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Learning Style of participants</td>
</tr>
<tr>
<td>2.</td>
<td>How the CAVE2™ or the Collaboration Studio was integrated in the learning sequence of the course. What was it used for? Was it lecturer controlled or student controlled? Were there opportunities to revise the artefact?</td>
</tr>
<tr>
<td>3.</td>
<td>Was there difficulty experienced in getting the artefact to function? How many times was your class exposed to visualisation technologies?</td>
</tr>
<tr>
<td>4.</td>
<td>What did you get out of using the visualisation technologies? Was your learning enhanced?</td>
</tr>
<tr>
<td>5.</td>
<td>How would you have improved the delivery of the visualisation technology?</td>
</tr>
<tr>
<td>6.</td>
<td>Expectations of the use of facilities prior to the first experience.</td>
</tr>
<tr>
<td>7.</td>
<td>Difficult content in the course. Suggestions for what would be the best course concept to create artefacts for and why?</td>
</tr>
<tr>
<td>8.</td>
<td>Do you think that would get more out of the course if the artefact was made more readily available for revision purposes?</td>
</tr>
<tr>
<td>9.</td>
<td>How was feedback used in your engagement with the artefacts?</td>
</tr>
<tr>
<td>10.</td>
<td>Do you feel that there is more value in the artefact versus the real world equivalent?</td>
</tr>
</tbody>
</table>
Results

The data collected was analysed thematically based on the following elements:

- Use of technology to enhance learning
- Use of Collaboration Studio or CAVE2™

**Themes from Observations of Focus Courses**

Observations of focus courses were undertaken to assess the lecturers teaching style and how the visualisation facilities were applied in meeting the course learning outcomes. Table 4 shows the observations in each focus course based on the style of teaching used and the use of the visualisation facilities.

**Table 4: Style of teaching and visualisation use in focus courses**

<table>
<thead>
<tr>
<th>Course</th>
<th>Style of Teaching</th>
<th>Visualisation Facilities Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Didactic</td>
<td>• Collaboration Studio</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Artefact – lecturer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>controlled</td>
</tr>
<tr>
<td>B</td>
<td>Interactive</td>
<td>• Collaboration Studio</td>
</tr>
<tr>
<td></td>
<td>Experiential</td>
<td>• Display wall was</td>
</tr>
<tr>
<td></td>
<td></td>
<td>used for screen-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>sharing purposes</td>
</tr>
<tr>
<td>C</td>
<td>Mix between</td>
<td>• CAVE2™</td>
</tr>
<tr>
<td></td>
<td>traditional</td>
<td>• Artefact – lecturer</td>
</tr>
<tr>
<td></td>
<td>lectures and</td>
<td>controlled but asked</td>
</tr>
<tr>
<td></td>
<td>experiential</td>
<td>questions that</td>
</tr>
<tr>
<td></td>
<td>style of teaching</td>
<td>demonstrated problem-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>solving ability.</td>
</tr>
</tbody>
</table>
Themes from face-to-face and online surveys

The surveys were conducted across all focus courses with the questions listed in Table 1. The results will focus on the responses to question seven (Table 1), the main themes of the responses in question five (Table 1), and the additional questions for each course (Table 2).

Figure 1 shows a summary of the student evaluations of the effectiveness of technology prior to the construction of the visualisation facilities. There was no past data available for course B.

Figure 1: Student evaluation of the technology use in course A (n=9), and course C (n=40) in semester one, 2015, prior to the construction of the USC visualisation facilities.

Figure 2 displays the student evaluations conducted towards the end of the semester based on the use of technologies in focus courses, in semester one, 2016.
Figure 2: Student evaluation of the technology use in course A (n=7), course B (n=17), and course C (n=33) in semester one, 2016 post-construction of the USC visualisation facilities.

Table 5 shows the results of a thematic analysis performed on the responses to question five – How did the use of technology in the course assist your learning – in focus courses. The themed responses to question five were merged with the themes emerging from responses to the additional questions (Table 2). Results were split based on the students’ earlier declaration if they agreed/strongly agreed or disagreed/strongly disagreed with the use of technology in the enhancement of their learning (question seven of the formal survey).
Table 5: Thematic analysis of responses to survey question 5 and additional survey questions

<table>
<thead>
<tr>
<th>Course</th>
<th>Students who agreed technology enhanced learning</th>
<th>Students who disagreed technology enhanced learning</th>
</tr>
</thead>
</table>
| A (n=7) | • No common themes (29%) | • Minimal impact on learning  
• Whiteboard was suggested to have been more effective than the technology used  
• Facilities did not impact on understanding  
• Not utilised frequently (71%) |
| B (n=17) | • Being able to use the collaboration studio screen supported students in their learning  
• Gave a better understanding of what was going on  
• Data for the course was more accessible and easier to display  
• Screen-sharing – Learnt from other people’s mistakes  
• Lecturer use of the Display wall was effective for learning  
• Participating in group work in the Collaboration studio enhanced learning and increased interactivity of lectures and tutorials (88%) | • No common themes (12%) |
| C (n=33) | • The CAVE2™ helped to visualise and understand forces affecting structures  
• The CAVE2™ helped visualise design projects and 3D concepts for problems  
• Accessibility – fun experience but would like to see more use of the CAVE2™  
• Visualisation facilities increased the rate of understanding (64%) | • Basic technology assisted in learning (Blackboard, calculators, PowerPoints, whiteboards etc.)  
• Technology used did not have a significant enhancement on learning  
• CAVE2™ visualisations consolidated knowledge from a previous course  
• Visualisation outcomes could have occurred in the classroom  
• CAVE2™ is amazing but use could be improved  
• 3D is unnecessary (36%) |
Learning with simulation technologies

Course A

In course A, there are notable differences between semester one, 2015 and semester one, 2016, following the inclusion of visualisation artefacts in the course curriculum as seen in figures 1 and 2. In semester one, 2015, 11.1% agreed and 33.2% disagreed that technologies assisted their learning where in semester one, 2016, 29% agreed and 71% disagreed in some capacity. A higher proportion of students agreed and disagreed in 2016 but this could be attributed to the removal of the “neutral” option on the Likert scale.

As noted in table 4, this course utilised a didactic approach to teaching. Lectures were teacher-centred and focussed on a traditional mode of instruction. There were limited opportunities for students to actively participate in learning activities (O’Neill & McMahon, 2005).

Course A utilised the Collaboration Studio for its lectures and an artefact was utilised in one lecture. When the artefact was used, it was lecturer controlled, and in relation to the I^3 framework, did not encourage interaction or immersion due to the limited opportunities for students to actively engage with the artefact. It also appeared to not foster imaginative thought as there was no platform for students to problem-solve (Huang et al., 2010).

Table 5 further indicates that for course A, the technologies in the course had a minimal impact on learning, however this could be attributed to the application of pedagogy incompatible with a simulation. Huang et al. (2010) notes that it is imperative for innovative pedagogy to be coupled with an integrated simulation to enhance learning outcomes.
Course B

In course B, no data was available for comparative purposes from previous semesters but in the formal survey, a majority of students agreed that the technological environment supported students in their learning.

This course utilised an interactive and experiential style of teaching which was noted by students displayed in table 5, to be an effective means of learning. Learners were encouraged to be responsible for their own learning through the student-centred nature of the learning environment and the collaborative problem-based activities that were facilitated (Fetherston, 2006; O’Neill & McMahon, 2005).

Course B utilised the Collaboration Studio for its lectures and workshops and did not use a visualisation artefact. However, the course was noted by students to have effectively used the visualisation facilities and in particular, the large high-resolution display wall to facilitate collaborative learning as seen in Figure 3. This application was considered to be imaginative, as the screen-sharing technology helped facilitate problem-solving activities (Huang et al., 2010).

There were more students who agreed than disagreed that the technology supported them in their learning. This could be further attributed to an appropriate pedagogical approach used in this course to suit the visualisation facilities; course B was noted to utilise an interactive and experiential approach as seen in Table 4 (Huang et al., 2010).
Course C

In course C, there are minor differences between semester one, 2015 and semester one, 2016, as seen in figures 1 and 2. In semester one, 2015, 45% of participants agreed in some capacity that technology enhanced learning, where 15% disagreed. In semester one, 2016, 64% of students agreed, where 36% disagreed. The higher proportions in the latter survey can be once again attributed to the removal of the “neutral” option from the surveys. The proportion who selected “agreed” in the 2015 survey is high, considering the visualisation facilities had not yet been constructed.

Course C utilised a mixed approach to teaching, synthesising traditional lecture instruction methods with experiential modes of learning. Based on student responses, this appeared to be an effective learning approach.

This course utilised the CAVE2™ in one class to expose students to a visual perspective of an engineering construct. The artefact use was lecturer controlled, but the lecturer encouraged students to predict what would happen. This prediction activity is a
form of problem-solving and a way to facilitate discussion, relating the artefact use to the imagination principle (Huang et al., 2010).

**Summary**

A number of factors influence the quality of learning. Based on the interrelationships between the themes gathered in the student evaluations, literature, and face-to-face targeted interview responses, Figure 4 illustrates that the lecturer, learner, the usage of the technology, and the artefact, all enhance the learning experience. Figure 4 also illustrates that a number of sub-factors impact on the effectiveness of the key influences of the integration of simulation technologies on learning.

Recommendations

The following recommendations listed in table 6 have been developed based on all instruments used to collect students experience and are a list of strategies to support the effective integration of simulation technologies, in Physics-related Engineering courses.

Table 6: Recommendations to support the effective integration of simulation technologies.

<table>
<thead>
<tr>
<th>Domain</th>
<th>Recommendation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecturer</td>
<td>Discussion</td>
<td>To implement engaging strategies to facilitate discussion – in contrast to saying “this concept is how it is”.</td>
</tr>
<tr>
<td></td>
<td>Assessment</td>
<td>To consider aligning visualisation experiences with assessment tasks.</td>
</tr>
<tr>
<td>Learner</td>
<td>Engagement</td>
<td>To consider strategies to increase interaction or opportunity to interact with learning material.</td>
</tr>
<tr>
<td></td>
<td>Can I do this?</td>
<td>To check in with students’ background knowledge and skills to make sure no barriers exist to learning.</td>
</tr>
<tr>
<td></td>
<td>Immersion</td>
<td>To use visualisation to elicit imagination.</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>To hand over control of artefacts to the learners in order to increase interaction.</td>
</tr>
<tr>
<td>Usage</td>
<td>Frequency of Use</td>
<td>To consider strategies to increase the usage of the visualisation facilities.</td>
</tr>
<tr>
<td></td>
<td>Revision</td>
<td>To incorporate strategies to allow students to revisit the technologies used for learning purposes.</td>
</tr>
<tr>
<td>Artefact</td>
<td>Problem-solving</td>
<td>To incorporate a problem-solving functionality in artefacts – students suggested that it would increase learning accountability.</td>
</tr>
</tbody>
</table>
**Limitations and Further Research**

The results contain limitations due to the phenomenological nature of the study and are not necessarily generalisable to all learners. There are also limitations present in the results when comparing semester one, 2016, survey data with previous semesters due to the removal of the “neutral” variable.

Further research is required in relation to more quantifiable measures of assessing the effectiveness of learning with the integration of simulation technologies. It is also suggested that the recommendations are implemented and subsequently evaluated to measure the effects on learning.

**Conclusions**

The notion of visualisation plays an important role in synthesising traditional forms of instruction with experiential and interactive methods of learning. It is important to be aware of the key influences on the effective delivery of simulation technologies and the effective use of the visualisation facilities on teaching and learning. The lecturer’s pedagogical strategies, the usage of the facilities, the learner, and the artefact itself are critical on learning in these facilities.

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References


