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Onsite and online: A 4-dimensional multi-disciplinary learning environment for construction industry professionals

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Abstract: Work-integrated learning has been suggested as a means to apply theoretical knowledge in a real-world context. Yet tensions exist between the opportunities afforded by the workplace, and the demands of placing large student cohorts in that workplace while ensuring pedagogical rigour. For students in construction-related disciplines, access to building sites to contextualise learning is a further problematic issue. This suggests opportunities exist for alternative approaches to providing the benefits of work-integrated learning through simulated real-life contexts. This paper reports on an Office for Learning and Teaching funded project that investigates this issue. The project involves the development of an interactive digital learning environment based on time-lapse 3-dimensional (4D) visualisation and other resources associated with the design and construction of the University of Queensland's Advanced Engineering Building. The 4D environment provides a realistic context for simulated problems that activate student learning using a collaborative problem-based approach to enhance critical thinking skills. A pilot version of the 4D environment has been trialled and interim results indicate that the 4D environment is flexible in terms of its use across different learning activities and disciplines, and that it enhances the learning experience in terms of developing observation, reflection and collaboration skills.

Keywords: Digital learning environments; immersive learning scenarios; construction industry.

1. Introduction

Addressing the imbalance between theory and practice to produce graduates who can engage effectively in their chosen professional settings is a recently recurring theme in higher education (Kek and Huijser, 2011, Litchfield et al., 2010). Work-integrated learning, where students apply disciplinary knowledge and skills in a real-world context, is one approach that seeks to address this issue (Billett, 2009; Orrell, 2011). However, in construction related industries such as architecture, the ability to contextualise learning as a realistic experience is hampered by the dangerous, fragmented and litigious nature of the industry (RCBCI, 2002; Safe Work Australia, 2012). There is also limited involvement of the tertiary sector in construction-related research. Innovations in the industry, therefore, have a tendency to be retained as proprietary knowledge for competitive advantage. Conversely, the generic body of professional knowledge has a tendency to remain static, standardised and largely theoretical (Johnson, 1972; Macdonald, 1995) with academics reporting that they have difficulty in maintaining an industry-relevant contemporary knowledge base (Ostwald and Williams, 2008).

Much has been made in the higher education literature of the advantages of work-integrated learning, both as a means to address the practical application in a real-world context of the disciplinary knowledge and skills gained in a classroom (Billett, 2009; Smith, 2012), and as a means to engage students in what it means to participate in a real work environment (Orrell, 2011). However, tensions also exist between the opportunities afforded by the workplace, and the demands of placing large student cohorts in that workplace whilst ensuring educational validity and pedagogical rigour (Lester and Costley, 2010). This suggests that opportunities exist for alternative approaches to the provision of work-integrated learning through an alternative technology-enhanced medium (Keppell *et al.,* 2011). While computer simulated virtual reality environments linked to gaming technology have been developed as educational platforms, there are limitations to the contextual realism and practical detail offered by such environments. An alternative approach is to create a virtual environment based on digital photographic images captured across the course of a 'live' construction project.

This paper reports on interim findings of an Australian Office for Learning and Teaching funded project titled 'Developing a 4-dimensional interdisciplinary learning environment for construction industry professionals'. The two-year project consists of four stages with the digital learning environment prototype currently being trialled across three Universities, five programs and seven courses. The following paper is structured to initially provide background to the challenges facing the construction industry and education. With this context in place, the paper then describes the 4-dimensional (4D) learning environment, including the various approaches to the use of that environment in the three courses that have trialled the prototype so far. The paper concludes with a summary of the results of a questionnaire survey administered to students involved in the initial trials.

2. Contextualising the learning environment

2.1. The challenges facing the construction industry

The construction industry is a significant sector of the Australian economy. In 2008-09, construction accounted for 6.8% of Australia's gross domestic product (GDP) making it the fourth largest contributor to GDP. In the same period, 984,800 people or 9.1% of the workforce were employed in construction related activities making it the fourth largest employing industry in the country (ABS, 2010). A further small but growing contribution is made by the sector to national export earnings, primarily in the area of specialist architectural and engineering consultancy services (DFAT, 2011). At a broader socio-environmental level, the construction industry has a further considerable impact on quality of life and the sustainability of that way of life, principally through the design of safe, liveable and energy efficient buildings and urban environments. Having a strong and innovative construction industry is, therefore, an important foundation for Australia's future.

Recent studies, however, suggest there are several fundamental flaws in the structure of the industry. In 2002, the Royal Commission into the Building and Construction Industry (RCBCI) described the industry as having a highly complex and competitive structure that limited innovation and contributed to poor productivity. Furthermore, the Commission noted that new construction projects were designed and managed on an individual basis and drew on a disparate range of skills that varied throughout the life of the project. The Commission concluded that the transient and multi-disciplinary character of construction projects, together with the fragmented nature of the industry and adversarial procurement methods, impacted on the capacity for innovation and continuous improvement across the construction supply chain (RCBCI, 2002). Recent industry figures and academic studies indicate little has changed. There continues to be a high number of small firms operating in the industry and a high degree of specialisation (IBISWorld 2012). There also continues to be concern about the capacity for innovation, particularly in relation to collaborative practices (Dossick and Neft, 2010), knowledge management (Sheriff *et al.*, 2012) and the integration of new technology (Love *et al.*, 2011a and 2011b).

2.2. Challenges facing education for the construction industry

In an extensive survey, Ostwald and Williams (2008) explored changes in the structure and content of architectural programs across Australasia, and the future challenges facing architectural education. The study concluded that curriculum 'overcrowding' (too much material), curriculum 'drift' (course isolation from foundational knowledge) and curriculum 'fragmentation' (non-design courses perceived to lack relevance) have undermined the teaching of core professional skills in architecture programs. While construction technology, one of four main curriculum areas, had maintained a relatively consistent weighting at 19-20% of coursework offered in an architecture program, the demands on technical content had changed significantly. There was also a perception amongst academic staff that maintaining industry-relevant knowledge was a problem. In a study of the advantages of immersive learning environments for engineering students, Cameron, *et al.* (2009) found that the loss of industry placements was having a further impact on the level of insight and appreciation of design and operational issues amongst undergraduate students.

An additional issue for the education of construction industry professionals is an expectation that graduates will be able to operate effectively as members of multi-disciplinary teams. The Oswald and Williams (2008) study reported that the design and assessment of group work was a growing educational challenge. This finding was reinforced by Tucker *et al.* (2014) who established that there was limited emphasis on the teaching of teamwork skills in architecture and related design programs. There was also limited understanding amongst academics of what leads to effective teamwork, and how to design curriculum that would enhance the learning of teamwork skills.

Finally, several studies have explored game-based computer simulated virtual reality learning environments. de Freitas and Neumann (2009), for example, reported that the self-directed nature of computer simulations had the capacity to empower learners. There is, however, still a need for structured activities and academic interaction to support the acquisition of primary knowledge before more open-ended exploration can be effective. Marcelino *et al.* (2010) found the level of user interaction to be a major strength of computer simulated environments. While an avatar navigating through a virtual world is interactive, navigating in learner teams through a live construction site provides a level of real complexity that further enhances a sense of collaborative immersion and experience relevance. More recently, Nadolski *et al.* (2012) argued that computer simulations support the acquisition of higher order skills more efficiently and effectively than traditional learning methods, despite acknowledging high initial costs and the need for research on the effectiveness of knowledge and skills transfer in different practical settings. To date, no studies have been found that focus on the development of a 3-dimensional learning environment using digital photographic images of a 'live' construction process over time (4-dimensions), and none have been found that compare computer simulated with photographic digital learning environments.

3. Developing the learning environment

In December 2013, a project team representing architecture and civil engineering at the University of Queensland, construction management at the University of Newcastle, and architecture at the University of South Australia were awarded a 2-year $220,000 Australian Government Office for Learning and Teaching (OLT) Innovation and Development grant. The primary goal of the project was to address problems associated with the provision of a realistic, practical and multi-disciplinary experience for students in construction related professional disciplines. The project was designed to build on an existing OLT funded 3-dimensional learning environment for process engineers developed by Professor Ian Cameron and others (Cameron *et al.*, 2009). The project utilised 75 high resolution, 3-dimensional digital photographic surveys undertaken at 1-2 weekly intervals (4-dimensions) throughout the construction of the University of Queensland's (UQ) Advanced Engineering Building (AEB).

The photographic surveys, and processing the surveys into an initial 4-dimensional digital learning environment prototype, were undertaken through a University of Queensland Teaching and Learning Strategic Grant. The photographic surveys utilised a Nikon D200 digital SLR camera with an AF DX 10.5 mm fisheye lens, and AF-S DX VR Zoom-Nikkor 18-200 mm and 55-200 mm digital lenses for general photographic work. The digital images were uploaded onto a computer at the conclusion of each survey. AutoPano Giga V2.6 software was used to stitch and render photographs taken at each survey node into large panoramic photos. PanoTour Pro V1.7 software was used for internode and equipment hot spotting, and the export of KrPano panorama XML files. KrPano software provided the 3D panorama functionality. Finally, Microsoft OneNote software was used to digitally mark-up the location of survey nodes on floor plans and a unique python script program was used to calculate node coordinates.

While documenting every aspect of the construction process as frequently as possible was a temptation, it was determined that this would ultimately reduce the effectiveness of the final 4-dimensional environment as a learning tool. Incremental changes to the overall construction site and progress on important building elements would become imperceptible. Navigating through the site once the data had been built into the software would also be difficult. To achieve a consistent and concise survey over the course of the construction period, the following rules were devised:

- Avoid capturing redundant and repetitive construction processes that deliver minimal educational impact and increase the processing workload and file storage requirements.
- Conduct a test survey to become familiar with the site and determine the ideal survey locations.
- Avoid survey nodes on temporary structures that become unavailable at a later point in time.
- Where a temporary obstruction does occur at a survey node, find the next best or closest location to continue the survey. Identify the original node to be revisited at a later point in time.

Comparison screenshots of the 4-dimensional learning environment are shown in Figure 1 (Survey 3 dated 7 June 2011) and Figure 2 (Survey 34 dated 7 March 2012). Figure 1 is taken from Level 2 and Figure 2 is taken from Level 6 of the building. Both shots are facing in the same southwest direction with Figure 1 taken at the edge of the construction site and Figure 2 taken from within the building itself. The timeline across the bottom right of the screen allows students to move chronologically between surveys, the plan at the bottom left of the screen allows navigation horizontally between several nodes on a particular level of the building, while the vertical bar between the plan and timeline allows navigation vertically between levels of the building. Within the learning environment, students can use a mouse to rotate each image 360 degrees horizontally and vertically, zoom in on particular areas to better assess detail, and enlarge the floor plan to move around the building.

Figure 1: 4D construction learning environment, Level 2 Node 6 dated 7 June 2011

Figure 2: 4D construction learning environment, Level 5 Node 2 dated 7 March 2012

In addition to self-directed access to photographic surveys that visually capture the construction process over time, the prototype has been expanded to incorporate other resources associated with the design and construction of the UQ's AEB (drawings, contract documents and interviews), as well as simulated problems to activate student learning (Francis and Shannon, 2013) using an immersive learning scenario approach to enhance critical thinking skills (Kek and Huijser, 2011). Additional resources are available using a drop-down menu. This particular project is unique in that it integrates 'factional' contract and project management resources, as well as interviews with key members of the design and construction project team, to enhance the real-life context. In so doing, the environment expands the existing 3-dimensional images into a multi-user 4-dimensional learning environment.

4. Methodology

The 4-dimensional learning environment adopted an 'exploratory learning' pedagogical model (de Freitas and Neumann, 2009) derived from Kolb's (1984) 'experiential learning' model. Kolb's original four-stage model defined a cycle of learning from concrete experience, to observation and reflection on that experience, to forming abstract concepts, before testing in new situations that in turn become concrete experiences. In Kolb's model, experience relates exclusively to 'lived' experiences. Technology-enhanced learning approaches, however, may relate to virtual experiences and 'transactional' learning, or set tasks designed as a choreographed, team-based learning pathway. The resultant five-stage model separates Kolb's second stage into exploration and reflection stages, emphasising the expanded role of social interaction in the immersive learning experience. Within this framework, the 4-dimensional learning environment has been utilised in a variety of ways across four disciplines and seven courses, from a self-directed learning resource to an immersive learning environment (Table 1).

Table 1: 4-dimensional learning environment pilot study participating courses and learning activities

Program and Year	Course Title	Learning activity
Year 1, Bachelor of Construction Management (Building)	Building Codes and Compliance (250 students, mixed-mode)	Evaluation of fire safety issues in an immersive learning context. Direct assessment of student comprehension using codes, construction drawings and 4D environment.
Year 1, Bachelor of Construction Management (Building)	Construction Technology 1 (350 students, mixed-mode)	Demonstration of site safety issues and construction processes in a lecture context. Indirect assessment of student comprehension using construction drawings and activity sequencing in the 4D environment.
Year 2, Bachelor of Engineering	Reinforced Concrete Structures and Concrete Technology (250 students)	Demonstration of concrete design and construction processes in a lecture context. Indirect assessment of student comprehension using construction drawings and activity sequencing in the 4D environment.
Year 3, Bachelor of Architectural Design	Architectural Technology 3 (98 students)	Evaluation of Building Code, structural, environmental and construction issues in an immersive learning context. Direct assessment of team-based comprehension using factional contract documents and the 4D environment.
Year 3, Bachelor of Architectural Studies	Architecture and Technology (99 students)	Demonstration of services and sustainable design integration in an immersive learning context. Direct assessment of team-based comprehension using construction drawings and the 4D environment.
Year 3, Bachelor of Construction Management (Building)	Construction Business Management (150 students, mixed-mode)	Evaluation of management actions in an immersive learning context. Indirect assessment of student comprehension using role-play, reflection, factional contract documents and the 4D environment.
Year 2, Master of Architecture	Architectural Practice 2	Evaluation of contract administration issues in an immersive learning context. Direct assessment of team-based comprehension using factional scenarios and the 4D environment.

The 4-dimensional learning environment project adopted an action research methodology (Easterby-Smith *et al.,* 2008) to ensure feedback was incrementally collected and fed back into the developing learning environment. The project was divided into four stages of approximately six-months each:

- Development – investigated alternative learning strategies and technology options, access to construction documentation and key personnel, and existing course curriculum.
- Usability trial – established how best to integrate other resources into the learning environment, devised new curriculum and assessment strategies, and trialled Version 1 of the 4D environment.
- Pilot study – embedded of other resources into the learning environment and conducted pilot trials of Version 2 of the learning environment.
- Evaluation – will see the incorporation of pilot study results into Version 3 of the learning environment and further trials before and finalisation of project.

5. Results – Prototype trial and pilot study

In Semester 2 2014, an initial usability trial of the 4-dimensional learning environment Version 1 was conducted with Year 3 Bachelor of Architectural Design students at the University of Queensland (UQ). The trial employed an in-class scenario-based activity each week for four weeks. Scenarios required students to access the 4-dimensional learning environment and observe specific structural, environmental and construction issues. The aim was to engage students in team-based problem solving and reflection on how particular construction activities are carried out, and specific building elements are fabricated. The scenarios also aimed to link those activities and elements to the 2-dimensional information communicated in construction drawings. This was followed in Semester 1 2015 by a pilot study with Year 3 Bachelor of Architectural Studies students at the University of South Australia (UniSA). The pilot study used Version 3 of the learning environment as an in-class demonstration tool and resource for additional self-directed student learning. Results from a five-item Likert-type scale and open-ended evaluation questionnaire administered to students are summarised below. Fifty-nine of 98 or 60% of students enrolled in the UQ course completed the usability trial survey, while 57 of 99 or 58% of students enrolled in the UniSA course completed the pilot study survey.

5.1. Appearance

In response to Question 1, ‘Did you like the appearance of the learning environment?’ 19% of UQ students and 33% of UniSA students strongly agreed, while a further 57% of UQ students and 63% of UniSA students agreed with the question. Question 5 was an open-ended question that prompted students to offer suggestions for future improvement. Positive responses were made about the realistic appearance of the site, rather than the appearance of the learning environment itself. Suggestions for improvement in the usability trial included increasing the size of the floor plan in the viewing pane and enabling different floor plans to be overlaid to show the relationships between them. This has been addressed in Version 3 of the learning environment. Further comments from both cohorts related to image sequencing with suggestions that images showing particular views should be taken from the same nodal position in each survey, and on each building level. This would enhance user orientation from survey to survey but cannot be undertaken retrospectively. The variable vertical and horizontal progress of construction activity also make it a difficult undertaking for any future case study projects.

5.2. Navigation

In response to Question 2, 'Did you find the learning environment easy to use?' 12% of UQ students and 28% of UniSA students strongly agreed, while a further 54% of UQ students and 63% of UniSA students agreed with the question. Navigation, or ease of use, generated significant written comment in the usability trial. Although intuitive, many described the environment as 'slow to load', and that it 'froze', 'stuttered' or 'crashed' during use. The node selection function on floor plans was similarly problematic and there were difficulties with the chronological survey selection function. Specifically, adjustments to the timeline slider caused the view to zoom out and the node to relocate on the floor plan causing confusion and frustration. These basic functionality issues were addressed in Version 3 and there were fewer comments about ease of use in the UniSA pilot study but several references were made to the consistency of node locations from survey to survey.

5.3. Content

In response to Question 3, 'Did you find the learning environment assisted your understanding of architectural technology?' 25% of UQ students and 23% of UniSA students strongly agreed with the question, while a further 56% of UQ students and 70% of UniSA students agreed with the question. Despite appearance and navigational issues, the positive impact of the learning environment on student understanding of the construction process was almost universally supported in both the Version 1 usability trial and Version 3 pilot study. Open-ended responses indicated that the environment provided more information than 2-dimensional photographs or ad hoc site visits, and was a useful tool for understanding the day-to-day operation of a construction site. Positive feedback was given in relation to enhancing understanding of construction sequencing, as well as the requirements of particular construction activities and specific building elements. Additional comments related to the way the learning environment revealed the building structure and architectural detailing, while the zoom feature enabled valuable close examination of particular details. The learning environment was also considered to aid comprehension through comparison of 2-dimensional construction drawings and 3-dimensional images. Suggestions for improvement included the incorporation of time-lapse videos of key construction processes to help bridge the 1-2 week gap between digital surveys.

5.4. Learning experience

Question 4, 'Did you find the learning environment enhanced the architectural technology learning experience and, if so, why?' resulted in 12% of UQ students and 23% of UniSA students strongly agreeing with the question, while a further 67% of UQ students and 66% of UniSA students agreed. Comments about the extent to which the environment enhanced the learning experience referred to the creation of a positive link between theory and practice, bringing the construction process to life, and helping to consolidate theoretical material presented in lectures. Some suggested concepts explained in lectures became easier to visualise 3-dimensionally after using the learning environment, while some in the usability trial commented that the learning environment facilitated group collaboration and discussion, which in turn enhanced their understanding of coursework material. The instant access from classroom to construction site was considered a positive, as was the capacity to re-visit the site and follow aspects of the construction process independently. Suggestions for improvement in the usability trial included more defined learning tasks with clearer aims and links to assessment. A guided tour was suggested as well as more detailed whole-of-class explanations of construction processes and building elements as students using the environment discover them. Respondents in the pilot study found the site to be a useful interactive visual aid that enhanced their comprehension, while the capacity to view 2-dimensional and 3-dimensional information together enhanced their understanding.

5.5. Improvements

Other suggestions from both the usability trial and the pilot studies included developing the learning environment for use on a tablet and providing additional building case studies of various scale and complexity. Having consistent node positions on each floor and across each survey was a common request as was including call-out labels to explain key construction processes and building elements.

7. Discussion

The 4-dimensional learning environment prototype has, thus far, been well received by students and academics in two different programs. The possibilities offered by the learning environment range from use as a simple demonstration tool for an academic delivering a conventional on-campus lecture through to an immersive learning scenario and assessment system requiring engagement with the full array of resources offered within the environment (contract documents, construction drawings, 4-dimensional images, and interviews with key project team members). It is apparent, however, that the learning environment used as a simple visual aid represents a shallow engagement with the pedagogical possibilities that it offers. While there are issues, such as dependence in pre-determined nodes and the consistency of node locations from survey to survey, the learning environment can provide genuine and cost-effective improvement over traditional lecture-tutorial activities but only when it is fully utilised and holistically integrated into the curriculum. 'Virtual' work integrated learning has the potential to satisfy, at least in part, student and employer demand for a balance between theory and practice, and provide work-ready graduates who have the capacity to engage immediately in their chosen professional settings. The benefits are, however, contingent upon the skilful integration of immersive scenario learning into those parts of the curriculum where their full benefit can be realised.

8. Conclusion

Work-integrated learning as a means to achieve a balance between theory and practice is a topical feature of higher education (Orrell, 2011; Smith, 2012). While work experience has had a long tradition, particularly in professional education, the pressure of student numbers and the need for pedagogical rigour have impacted on the opportunities available for students to spend time in workplace settings of relevance to their degrees. In construction-related professions, workplace health and safety concerns have an additional impact on student access to 'live' building sites. Within this context, opportunities exist to explore alternative ways of providing the benefits of work-integrated learning through simulations of real-life contexts. Although studies have explored computer simulated virtual reality environments, none have focussed on the development of a 4-dimensional learning environment based on a 'live' construction project. The OLT funded project outlined in this paper is an attempt to provide such an environment for the education of construction industry professionals.

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