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Enhancing learning for construction industry professionals with a 4-dimensional digital learning environment

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Work-integrated learning has been suggested as a means to apply and learn disciplinary knowledge and skills in a real-world context. Tensions exist, however, between opportunities afforded by the workplace and the demands of placing large student cohorts in that workplace while ensuring equitable learning experiences and pedagogical rigour. This suggests there are opportunities to explore alternative approaches to providing the benefits of work-integrated learning through simulated real-life contexts. This paper reports on preliminary results from an Office for Learning and Teaching funded project that investigates this issue. The project involves the development of an interactive multi-disciplinary digital learning environment based on time-lapse 3-dimensional (4D) photographic images and other resources associated with the design and construction of the University of Queensland's Advanced Engineering Building. The 4-dimensional environment provides a realistic context for a variety of immersive learning scenarios designed to facilitate a flow of learning experiences that deepen conceptual thinking and enhance critical judgement. An initial learning environment prototype has been trialled and assessed using observational studies and informal feedback mechanisms. In an action learning process, trial results will be fed back into further pilot studies of the environment in 2015. Results indicate that the 4-dimensional learning 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

Introduction

A recurring theme in higher education is how to best achieve a balance between theory and practice and produce graduates who are ready to engage immediately and effectively in their chosen professional settings. In an industry such as construction, this theory-practice nexus is further complicated by the sector's competitive and fragmented nature, and the limited

involvement of higher education institutions in construction-related research. The result is that practical innovations in the industry have a tendency to be retained as proprietary information for competitive advantage, while the generic body of professional knowledge has a tendency to remain static, standardised and theoretical (Johnson, 1972; Macdonald, 1995).

Further compounding the achievement of an acceptable theory-practice balance in construction-related professional education is the inherently dangerous nature of the industry. In 2009-2010, construction was noted as one of four industries with serious workers' compensation claim and worker fatality rates substantially above the national average (Safe Work Australia, 2012). As a result, student access to construction sites is a problematic issue and one that further limits the ability of educators to contextualise learning as a realistic multi-disciplinary problem-based experience. Much has been made in the higher education literature of the advantages of work-integrated learning as a means to address the practical application of disciplinary knowledge and skills in a real-world context (Billett, 2009; Smith, 2012). Tensions continue to exist, however, between the opportunities afforded by the workplace, and the demands of placing large student cohorts in that workplace while ensuring equitable learning experiences and educational rigour (Lester & Costley, 2010). These tensions suggest that opportunities exist to explore alternative ways of providing the benefits of work-integrated learning through simulations of real-life contexts. It is within this context that the following paper reports on the development of a multi-disciplinary 4-dimensional digital learning environment for construction industry professionals.

The construction industry

The construction industry continues to be 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, 2012a; 2012b; 2012c). There also continues to be concern about the capacity for innovation, particularly in relation to collaborative practices (Dossick & Neft, 2010), knowledge management (Sheriff, Bouchlaghem, El-Hamalawi, &

Yeomans, 2012) and the integration of new technology (Love, Edwards, Goh, & Han, 2011; Love, Edwards, & Wood, 2011).

In relation to the education of construction industry professionals, Ostwald and Williams (2008) explored changes in the structure and content, and the challenges facing architectural education. Their study concluded that curriculum ‘overcrowding’ (too much material being delivered in a course), ‘drift’ (isolation of a course from foundational knowledge domains in response to overcrowding) and ‘fragmentation’ (where non-studio based courses in particular are perceived to lack discipline 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 an architecture program, the demands on content had changed significantly. There was also a perception amongst academic staff that maintaining industry-relevant knowledge and skills was a problem. In a study of the advantages of immersive learning environments for process engineering students, Cameron, et al. (2009) noted the loss of industry cadetships as having an impact on the level of insight and appreciation of design and operational issues amongst undergraduate students.

An additional issue highlighted by Oswald and Williams relates to the professional expectation that graduates will be able to operate effectively in groups. The study found the assessment of group work to be a growing educational challenge. A disjunction was also found to exist between student and academic views about the value of group work. While the Ostwald and Williams study highlights the need to enhance student engagement with construction technology and develop relevant approaches to teamwork and collaboration, it does not provide guidance on effective strategies. Finally, while there have been studies that have explored immersive virtual reality learning environments (see Cameron, et al., 2009; de Freitas & Neumann, 2009; Marcelino, de Silva, Alves, & Schaeffer, 2010; Nadolski, Hummel, Sloomaker, & van der Vegt, 2012), none has focussed on the development of a 4-dimensional learning environment or the integration of multi-disciplinary learning activities into that environment.

A 4-dimensional learning environment for construction industry professionals

In December 2013, a project team representing architecture and civil engineering from the University of Queensland, construction management from the University of Newcastle, and architecture from the University of South Australia was 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., 2007). The project was also designed to utilise 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 a 4-dimensional digital learning environment prototype, were undertaken through a University of Queensland Teaching and Learning Strategic Grant.

For comparison, screenshots taken from the 4-dimensional learning environment prototype 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 southwest 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, and 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

The aim of the project reported on in the remainder of this paper is, therefore, to improve the balance between theory and practice in the construction industry, specifically in the architectural, building surveying, construction management and engineering professions. The key strategy used to achieve this is an expansion of the existing digital learning environment prototype. In addition to self-directed access to 75 photographic surveys that visually capture a construction process over time, the prototype is being expanded to incorporate other resources associated with the design and construction of the UQ AEB (drawings, contract administration documents and interviews) as well as simulated problems that activate student learning (Francis & Shannon, 2013) using an immersive learning scenario approach to enhance critical thinking skills (Kek & Huijser, 2011). This particular project is distinct from earlier work in that it focuses on a multi-disciplinary use of the environment. It also integrates ‘factual’ building 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.

Methodology

The project foundation is a building case study that provides 4-dimensional digital images (3-dimensional photographic images captured over the duration of the construction process) of a ‘real-world’ construction project. The case study images are used to contextualise technical learning (Billett, 2009) and learning activities, based on real-world problems encountered over the course of construction. The case study is also used to expose students to the

complexities of multi-disciplinary teamwork and the demands of creative problem-solving normally encountered during ‘live’ work experience (Lester & Costley, 2010). The 4-dimensional digital images are yet to be linked to multi-user immersive learning scenarios. Immersive learning scenarios are referred to here as:

. . . serious games that are centred around authentic tasks, that provide artificial and/or real environments that challenge and make learners curious, that have appropriate and unambiguous outcome goals, and provide learners with clear, constructive, and encouraging feedback. Authentic tasks are immersive in nature and enable the acquisition of higher order skills in higher education, often involving collaboration between learners. (Nadolski et al., 2012)

The use of immersive learning scenarios is intended provide a stronger and more consistent pedagogical link to academic aims and objectives than guest lectures delivered by professional consultants or unstructured work experience, the traditional methods of practice-based knowledge transfer utilised in construction-related disciplines (Smith, 2012). The project is being undertaken in four stages outlined in Table 1 with Stages 1 and 2 having already been completed.

Table 1: Immersive learning scenario activities

Stage	Period	Activity
1. Development	January-June 2014	Investigate breadth, depth and access to other construction project resources such as drawings, contract administration documents and key personnel. Review existing course curriculum and assessment.
2. Usability trial	July-December 2014	Determine how other resources might be utilised. Develop new curriculum content and scenarios. Conduct Semester 2 trial of prototype and evaluate. Review learning environment design and interface.
3. Pilot study	January-June 2015	Conduct interviews with key personnel. Embed scenarios and other resources in expanded learning environment. Conduct Semester 1 pilot study and evaluate.
4. Evaluation	July-December 2015	Incorporate pilot results into Semester 2 courses. Conduct Semester 2 pilot study and evaluate. Incorporate pilot results into all courses. Finalise project dissemination and reporting.

The project proposes the use of a ‘lectorial’ format. Modified lectures continue to be used to present and explain a specific body of knowledge in a concise and organised manner. Lecture content is planned as a logical sequence of 15-20 minute ‘chunks’ or segments related to the construction process, and desired learning outcomes and assessment requirements. The focus of each segment is on delivering basic core knowledge related to building regulation, construction processes and detailing, materials, environmental and production technology, and project management as they relate to a medium scale, technically complex contemporary building. So as to choreograph a flow from core knowledge delivery to knowledge consolidation and application, each lecture segment is followed by a 15-20 minute interactive in-class tutorial-type activity based on immersive learning scenarios linked to the 4-dimensional learning environment (de Freitas & Neumann 2009).

The immersive learning scenarios utilise problem-based learning and role-play as a means to develop critical thinking skills (Kek & Huijser, 2011), collaborative analysis and decision-making capabilities (Joham & Clarke, 2012), and a capacity to work with ambiguity (Parton & Bailey, 2008) and non-linear real-world problems (Hanney & Savin-Baden, 2013). Tutorial segments focus on the application of principles to design and construction problems through a controlled sequence of introduction, problem posing, problem solving, reporting and consolidation (Kek & Huijser, 2011). The tutorial activities are based on real-life scenarios derived from the building case study. Students are required to access additional supporting material including construction drawings, ‘factional’ contract administration documents such as minutes of meetings and project reports, and interviews with key construction project participants, such as architects, structural engineers and project managers. The proposed Stage 3 and Stage 4 use of the 4-dimensional learning environment across four disciplines and seven courses are described in Table 2.

Table 2: Immersive learning scenario activities

Program and Year	Course Title (approximate numbers)	Proposed activity (Semester 1 or Semester 2 2015)
Year 1, Bachelor of Construction Management (Building)	Building Codes and Compliance* (250 students)	Evaluation of fire safety issues in an immersive learning scenario context. Direct assessment of student comprehension using the Building Code, construction drawings and the 4D environment.
Year 1, Bachelor of Construction Management (Building)	Construction Technology 1* (350 students)	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 (100 students)	Evaluation of Building Code, structural, environmental and construction integration in an immersive learning scenario context. Direct assessment of student comprehension using Building Code, factional contract documents and the 4D environment.
Year 3, Bachelor of Architectural Studies	Architecture and Technology (100 students)	Evaluation of building function, services and sustainable design integration in an immersive learning scenario context. Direct group-based assessment of student comprehension using construction drawings and the 4D environment.
Year 3, Bachelor of Construction Management (Building)	Construction Business Management* (150 students)	Evaluation of actions in an immersive learning scenario context. Direct assessment of student comprehension using role play, reflection in and on action, factional contract documents and the 4D environment.
Year 2, Master of Architecture	Architectural Practice 2 (60 students)	Evaluation of contract administration issues in an immersive learning scenario context. Direct group-based assessment of student comprehension using role play, factional contract documents and the 4D environment.

Note: * Includes face-to-face and distance students.

Finally, all aspects of the project are being evaluated iteratively throughout the duration of the project. An action learning process has been adopted to ensure that feedback is incrementally collected, reflected upon and fed back into the project development process. Evaluation strategies focus on three levels:

- Level 1, the *processes* used to achieve the final project outcomes (the 4-dimensional learning environment and associated immersive learning scenarios and materials);
- Level 2, the *usability* of the 4-dimensional learning environment (appearance and ease of use); and
- Level 3, the educational *impact* of the 4-dimensional learning environment (on learning outcomes for students and on teaching practice for staff).

In line with OLT requirements, an external evaluator is being used to evaluate final project outcomes and the processes used to achieve those outcomes. Usability issues have already been informally evaluated in a Semester 2 2014 trial of the learning environment prototype. Further evaluation will take place in a series of multi-disciplinary pilot studies throughout 2015. Usability and educational impact will be assessed using student questionnaires, observation studies and focus groups. An evaluation matrix will cross-reference the three levels of evaluation strategy described above against the following five elements of successful projects:

- Criterion 1, effective project leadership and management;
- Criterion 2, effective project team member contributions and institutional support;
- Criterion 3, clear goals and shared understanding of outcomes and processes;
- Criterion 4, effective guidance from the Project Advisory Group; and
- Criterion 5, effective dissemination of project outcomes and findings.

Results – Usability trial

An initial usability trial of the 4-dimensional learning environment prototype was conducted as part of Stage 2 of the project. Students of the Year 3 Bachelor of Architectural Design course Architectural Technology 5 at the University of Queensland were asked to engage with the learning environment prototype (i.e. the environment without embedded learning scenarios and other resources) and provide feedback on its use and impact. A series of in-class scenario-based activities were set each week for four weeks. The scenarios required students to access the 4-dimensional learning environment and make observational reports about specific structural, environmental, construction detailing and building process issues. Students were provided with specific survey dates on which to access the site, as well as building floor plans and sections relevant to the issue to be observed, and a description of the building element/s to be examined. 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 construction activities and building elements to the 2-dimensional information communicated in construction drawings.

In addition to observations of student interactions with the learning environment and informal questioning during activities, students were asked to participate in an informal survey for quality assurance purposes. Each student was asked to apply the knowledge gained from the group activities to an individual student assignment, a technical report related to a concurrent design project, and a group assignment requiring the production of construction drawings for a selected design project. Further evaluation of the educational impact was obtained through lecturer evaluation of assessment items. Student feedback over the four-week trial was categorised in relation to following four aspects of the learning environment prototype:

1. *Appearance* – Positive comments were made about the realistic appearance of the site rather than the appearance of the learning environment itself. Suggestions for improvement included increasing the size and prominence of the floor plan in the viewing pane, and enabling floor plans of different levels to be overlaid to show the relationships between them. This has since been addressed in Version 2 of the learning environment. Further comments 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. While this would enhance user orientation from survey to survey, this cannot be undertaken retrospectively with the current building case study. The variable vertical and horizontal progress of construction activity also makes it a difficult undertaking in future case study projects.
2. *Ease of use* – Navigation generated significant comment. Although intuitive, few students found the learning environment easy to use. Many described the environment as ‘slow to load’, and that it ‘froze’, ‘stuttered’ or ‘crashed’ during use. The node selection function on the floor plans was similarly problematic. Suggestions for improvement included the provision of more nodes and an indication of the optional viewing positions on each floor plan. Several students also mentioned difficulties with the chronological survey selection function. Specifically, any adjustment to the timeline slider caused the view to zoom out and the node to relocate on the floor plan causing some confusion and frustration.
3. *Content* – Despite appearance and navigational issues, the positive impact of the learning environment on architectural technology understanding was almost universally supported. The environment was generally considered to provide more information than 2-dimensional photographs or ad hoc site visits. Positive comments were made about how useful it was to see the way the site was organised (e.g. truck turning areas, crane locations and general logistics). Positive feedback was also given in relation to enhancing understanding of the overall sequencing of construction, as well as the requirements of particular construction activities (e.g. pouring concrete) and specific building elements (e.g. fabrication of concrete columns and floor slabs). Additional comments related to the way the learning environment revealed the building structure and the implications of architectural detailing, while the zoom feature enabled valuable close examination of particular details. Some students commented on the usefulness of comparing construction drawings and digital images in the learning environment for developing their understanding. 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.

4. *Learning experience* – Comments about the extent to which the environment enhanced the learning experience suggested it created a positive link between theory and practice, brought the construction process to life, and helped to consolidate theoretical material presented in lectures. Some suggested that concepts explained in lectures became easier to visualise 3-dimensionally after using the learning environment, while several commented that the learning environment facilitated group collaboration and discussion, which in turn enhanced their understanding of the coursework material. The instant access from the classroom to a construction site situation was also considered a positive. Suggestions for improvement included more defined learning tasks with clearer aims and a more direct link to assessment. Students generally felt that the site provided a good visual aid but that a more directed teaching approach would improve learning and prevent students ‘getting lost’. A guided tour was suggested, as well as more detailed whole-of-class explanations of key construction processes and building elements as students using the environment discover them.
5. *Improvements* – Other suggestions included developing the learning environment for use on a tablet and providing additional case studies of buildings of various scale and complexity. Based on the trial results, an expanded learning environment is currently being developed for piloting in 2015. Basic appearance and navigational issues raised in the usability trial will be addressed while structured immersive learning scenarios and supporting resources will also be incorporated into the learning environment. Figure 3 provides a diagrammatic representation of the proposed developments.

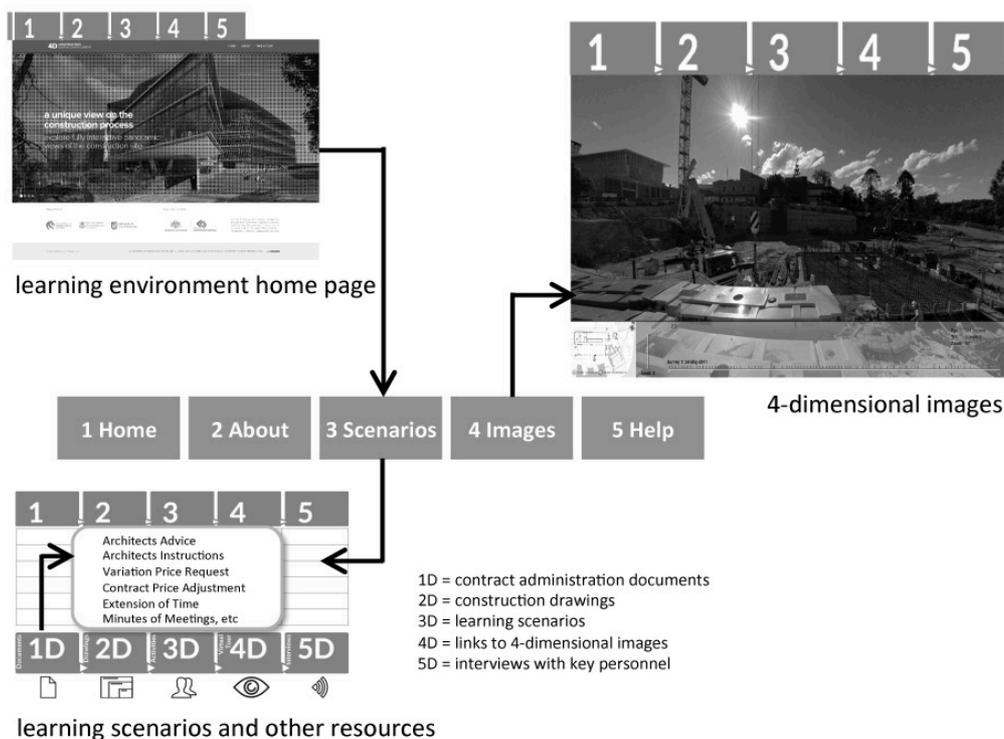


Figure 3: 4D construction learning environment, version 2

Conclusion

Work-integrated learning as a means to achieving a balance between theory and practice is an increasingly common feature of higher education, in Australia and elsewhere (Orrell, 2011; Smith, 2009). Work experience has had a long tradition in professional education in particular. However, the pressure of large student numbers and the need for pedagogical rigour have impacted on the opportunities available for students to spend time in work or other practice settings relevant to their degrees. In the construction-related professions, workplace, health and safety concerns have an additional impact on student access to buildings sites. Within this changing context, opportunities exist to explore alternative ways of providing the benefits of work-integrated learning through simulations of real-life contexts. Although there have been studies that have explored virtual reality environments and immersive learning scenarios, none have focussed on the development of a 4-dimensional learning environment or the integration of multi-disciplinary learning activities into that environment. The project presented in this study is an attempt to provide such an environment for the education of construction industry professionals.

The initial usability trial of the 4-dimensional learning environment prototype has been well received by students and academics across four construction industry professions. The possibilities offered by the learning environment range from its use as a simple demonstration tool for an academic delivering to an on-campus class in a conventional lecture context through to an immersive learning scenario and assessment system requiring engagement with the full array of resources offered within the environment (contract administration documents, construction drawings, 4-dimensional images, and video interviews with key design and construction project team members). It is apparent, however, that the learning environment can be used as a simple visual aid, representing a shallow engagement with the pedagogical possibilities it offers. The learning environment can offer genuine improvement over traditional lecture-tutorial activities but only when it is both 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 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.

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