A Situation Engine for Teaching and Learning Residential Construction Technology

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Teaching and learning residential construction technology is fundamental to any program of study in building and construction. Situated learning represents a model of education where practical experience of the work situation is core. A Situation Engine is an application that provides for specific and managed practical building and construction experience to be made available to students through advanced digital technologies. The rationale and development methodology for a prototype Situation Engine specific to teaching and learning residential construction technology is described. The prototype is in the process of being evaluated with 1st year construction management students and is discussed in that context.

Key Words: Residential construction technology, Situated learning, Serious video games

Introduction

A recent review of building and construction education in Australia identified that the specific teaching and learning of construction technology constitutes on average more than 25% of the total undergraduate curriculum content (Williams et al., 2009, p.20). Understanding the design and practice of construction technology remains a significant component of the core skills and competence requirements specified by professional accrediting bodies in building and construction (see for example, RICS, 2009). In the UK, construction processes are identified as a key concept in The Quality Assurance Agency for Higher Education subject knowledge benchmark statements for construction, property and surveying (QAAHE, 2008, p.4). In Australia, the integration of construction technology is identified explicitly as a Threshold Learning Outcome in the current Learning and Teaching Academic Standards project specific to building and construction (Newton & Goldsmith, 2011, p.5). Teaching and learning construction technology remains fundamental to building and construction education.

Situated learning offers a particular orientation to teaching and learning that privileges a more traditional approach to the mastery of professional knowledge and skills (learning) (Lave & Wenger, 1991). It has a direct and explicit focus on the personal observation of, and participation in, how practitioners actually ‘do’ their work (Wenger, 1998). That is to say, that under the rubric of situated learning, the learner is required to engage (directly) with (and in) the socio-cultural practices that constitute a particular domain of professional practice. In this context, the socio-cultural practices are the shared routines, sensibilities, vocabulary, styles, artefacts, procedures, etc. that the people who comprise a particular professional group have developed over time (Wenger, 1998). This is what Schön (1983, p.138) refers to as the language, media and repertoire of a particular professional practice. In conceptual terms, situated learning represents a return to something more akin to the apprenticeship model of education. In practical terms, situated learning represents a model of education where practical experience of the work situation is core.

Class sizes are increasing, occupational health and safety regulations are being tightened, work placements and internships are more difficult to resource. The temporal nature of construction means that particular aspects of construction technology are not always active when sites are visited. As a consequence, it is becoming increasingly impractical to offer direct student exposure to the broad practices of construction technology in a realistic setting (Mills et al, 2006). Construction technology education has responded to these increasing limitations placed on the provision of practical experience through a variety of teaching method innovations. We see new forms of course material, including: problem-based learning, project-based learning, invited guest speakers, videos, interactive multimedia, physical models, labs, field trips and simulation exercises. For example, a mix of Computer-Aided Design (CAD), Building Information Modeling (BIM), QuickTime VR, video and multimedia has been developed in various ways as virtual substitutes for a variety of practical experiences such as actual site visits, understanding physical building components and simulating specific construction processes (Sylvester, 2011; Glick et al, 2010; Horne & Thompson, 2008; Ellis et al., 2006). Such initiatives can certainly provide more effective demonstrations of the knowledge and skills required in very specific situations. They are also beginning to challenge traditional (knowledge-based) written and oral assessment methods and enable students to practice and demonstrate the skill-based learning outcomes (competence) that require students to complete actual activities in authentic situations (Walters & Sirotiak, 2011; Newton, 2009).

This paper reports on one initiative that draws on the full range of possibilities offered through emerging technologies to provide aspects of both teaching and learning and practice and demonstration using a new conceptualisation of what is here termed a ‘Situation Engine’. A Situation Engine is an application that provides for specific and managed practical building and construction experience to be made available to students through advanced digital technologies. The concept of an ‘engine’ is one where the same system is capable of being used to drive a variety of different ‘situations’ in a variety of ways. A ‘situation’ in this context is proposed as an alternative conception to ‘problems’ and ‘projects’ as the basic pedagogical framework for learning. The intention is to recognise and promote a focus on the experiential aspects of an exercise. An exercise will be more ‘situational’ when particular problems are not prescribed, but emerge from engagement in the exercise. More ‘situational’ where the project is not abstracted with a clear start and finish point, but is contextualised within a rich environmental setting. An initial prototype Situation Engine for teaching and learning residential construction technology has been developed and is being trialled with 1st year construction management students as the initial phase of a 2-year funded teaching and learning research project. This paper reports at the end of year 1 of that project.

Context of Course

The target curriculum for the current Situation Engine development is the 1st year course of a 4 year program of undergraduate study in construction management and property. The course is the first in the program of study to introduce students to construction technology. It deals with the functional requirements and construction methods specific to single-storey residential/domestic construction typical in Australia. As such the course examines a range of key technical aspects, including: brick and timber frame construction methods and materials; domestic joinery; staircase construction; finishes; plumbing, drainage and electrical services; methods of setting out and supervision. The course also involves developing skills in on-site observation and the production of housing site reports.

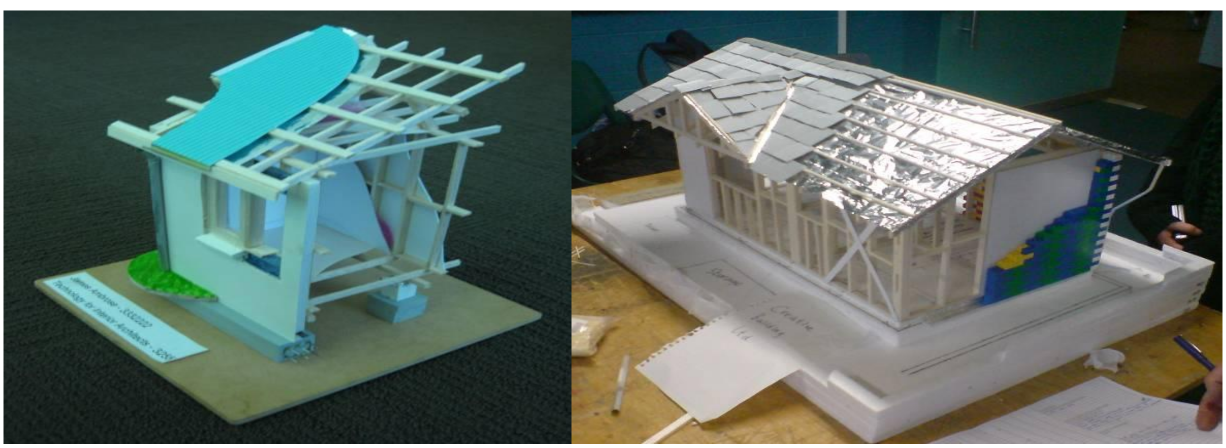

Figure 1: Examples of 1st year student scale model outcomes for residential/domestic construction technology.

A number of teaching innovations have already been implemented in this course. For example, the major assessment task requires students to work in teams to construct a physical 1:10 scale model of a house from a set of drawings (see, Forsythe, 2009). The introduction of this physical building exercise aims to provide direct and tactile student experience of how design drawings convert to physical outcomes. Figure 1 illustrates something of the range of possibilities achievable using a physical model-building approach. Students certainly experience the dynamics of group management, subcontracting, communications and time scheduling. However, the utility of this approach in terms of teaching and learning technical skills often depends as much on the generic model-building capabilities of the student as it does on their technical competence in construction technology.

The lecture material has also been extensively illustrated using Google SketchUp models to illustrate construction details during class and allow students to investigate those details in 3D outside of class. Figure 2 illustrates the broad level of detail being presented. These relatively simple 3D representations use colour-coding to highlight critical elements or distinguish between the likes of damp-proofing and mortar courses.

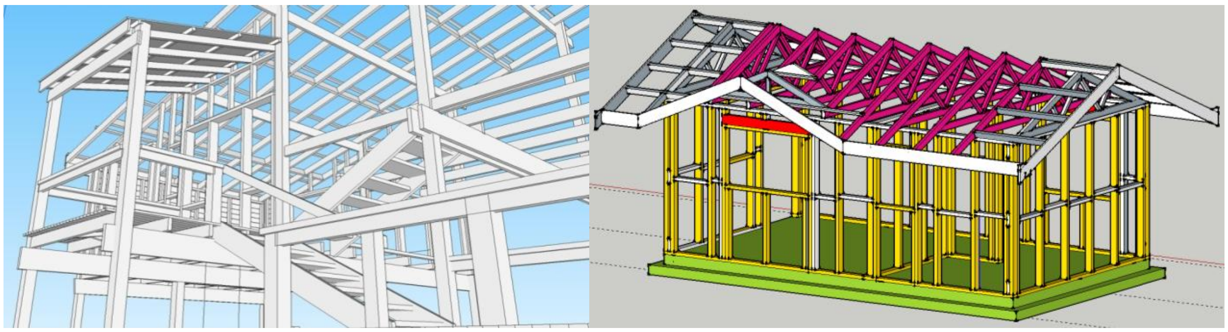

Figure 2: Extensive use is made of Google SketchUp models to illustrate details and support teaching.

The main objective of the prototype Situation Engine is to complement the existing course curriculum and assessment tasks by offering improved visualisation of the relevant construction technologies along with a more genuine ('situated') experience of the physical building exercise. Of course the use of a Situation Engine entails its own set of generic capabilities, and learning how to use the model does not of itself demonstrate technical competence in domestic construction. We are simply claiming that the skills required to use the Situation Engine are less prohibitive than those required to build a physical model when it comes to demonstrating technical competence in domestic construction.

Method

The design, development and evaluation of any teaching and learning resource demand an effective framework. The development of the Situation Engine is being framed using the concept of a learner centric ecology of resources, as proposed by Luckin (2010). In this theory, the learner is placed at the centre of three dimensions: the skills and knowledge to be learned, the resources available to support learning, and the environment within which learning occurs. The relationship of each dimension to the learner is then filtered through a particular delivery medium: knowledge is filtered through the particular design of the curriculum; available resources are filtered through the particular way those resources are administered and made available to the learner; and the environment is represented to the learner through the particular organisational structure within which they learn.

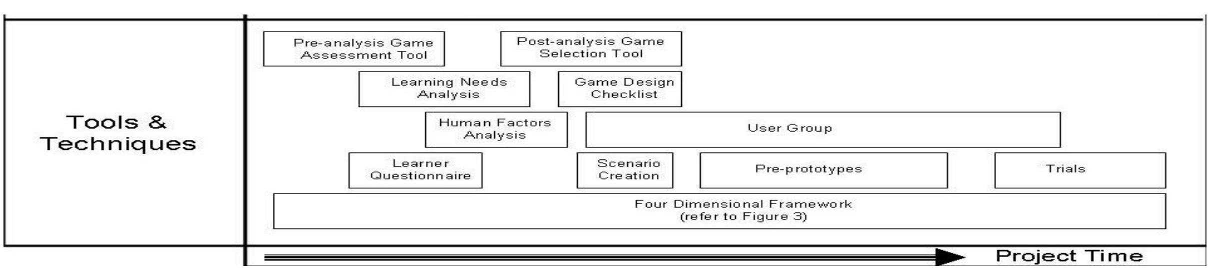

Figure 3: Extract of the integrated learning technology development framework adopted for

this project (de Freitas & Jarvis, 2006, p.5).

A further dimension to all elements recognises that each aspect emerges from and impacts upon the broader historical/cultural learning background, against which they must be set. More specifically, the development and testing method is based on the four-dimensional framework articulated by de Freitas & Oliver (2006). It draws also from commercial technology development (Adams, 2010) with particular enhancements to recognise the unique factors required by the learning and teaching context (Woods, 2004). This integrated approach is illustrated in Figure 3. The integrated approach helps promote key user requirements as critical success factors that punctuate the classical, strongly iterative analysis-synthesis-evaluation design and development process. The project has attended to all aspects of Figure 3, but for the purposes of this paper we describe only a selection of the steps involved.

Pre-Analysis Assessment

The pre-analysis assessment took the form of a comprehensive literature review of current applications of digital technology to support construction technology teaching and learning. It also reviewed a number of candidate technologies for the Situation Engine, most particularly the various genres of video game engines. It is evident that the most sophisticated interactive virtual reality simulation environments are to be found in video games. Video games use high performance graphics engines to render moving photo-realistic scenes in real-time and 3D along with the potential for associated surround-sound audio and tactile feedback to a user who controls the action with a variety of input devices. The 'action' is in fact variously controlled not only through input devices, but also by the particular rules and properties 'coded' into the video game by the developer. Such coded rules and properties are now extremely sophisticated, and many incorporate models of real-world mechanical behaviours ('physics engines') that simulate physical properties such as mass, gravity, velocity, volume, etc. in particular detail. Objects in such games can variously be opened, pushed, bent, lifted, broken and/or be used to trigger a myriad of other actions. Artificial intelligence and social dynamics are also now being modelled and incorporated into video games to simulate agency and group behaviour in different game 'actors'.

What is particularly timely about the potential development of video games for learning and teaching, is the recent development in video game technology that has resulted in the 'game engines' themselves (the kernel of coding used to drive a collection of actual game implementations) being made available on an open-source basis. Even the most powerful game engines are now relatively cheap to buy, are intentionally configured to allow third party modifications to be created and embedded seamlessly into the game engine, and are increasingly supported online by a significant and committed community of users and developers.

Several examples of 'serious video games' (a serious video game is one designed for a primary purpose other than pure entertainment) have now been developed as modifications to game engines across a range of game genres. For example, 'vehicle simulation engines' have been used to train and test vehicle operators from fighter pilots to crane drivers (Rouvinen et al, 2005); 'strategy game engines' are variously used for teamwork and project management training; 'business simulation games' model economic and manufacturing environments. This literature review identified a specific genre of video game known as a 'first person shooter' (FPS) game as the most relevant for a Situation Engine. FPS games are characterised by the use of an avatar which allows the user to see and be seen as a person would conventionally occupy a space (ie. bound to one's own body). Other game genres take a more abstract form of engagement (such as command-driven controls) or tend to focus more on the interactions and communications across a social network (such as in second-life worlds) rather than exercising specific technical competences. The prototype Situation Engine has been built using the proprietary video game engine CryENGINE2, a first person shooter genre, using modifications and extensions of existing functionality. CryENGINE2 is the development technology of choice because it features more advanced graphical, physical and animation technologies than most others (for further information, see http://www.crytek.com/cryengine). It is part of the open-source initiative, with a loyal and committed support community, and already has many game play and development enhancements available.

Establish Information and Communication Technologies Capabilities

Any high-end computer application is going to raise a number of concerns and problems for potential adopters at the institutional, teacher/tutor and learner levels. At the learner level, there are always issues of equity raised when students are required to use a novel learning technology because not everyone relates to a particular technology equally. Particular care was taken to provide the necessary exercises and tutorial material specific to the Situation Engine implementation. Many students need to scaffold their effective use of such technologies. There is already a substantial body of online tutorial material associated with the generic interface and use of CryENGINE2 available within the public domain. More specific tutorial support material for the domestic construction technology application will be developed as part of the second phase of system evaluation.

The main challenge for the dissemination of this technology is likely to be at the institutional level. Video game technology puts particular demands on computer capabilities, particularly in terms of the graphics processing power. Particular attention is given to the production of documentation aimed at the technical computer support required for the deployment and subsequent maintenance of relatively sophisticated video game engine applications across a range of different computer lab configurations. The project group has significant experience in this regard having facilitated over 250 first year students per year for several years to utilise a complete suite of the software required. Effective download speeds and the amount of internet traffic generated by such high-end graphics do, however, remain an issue.

Learning Needs Analysis

A formal process of human factor analysis using focus groups and task analysis has been undertaken, along with an analysis of the learning needs of current students. The learning needs were assessed by reviewing the performance of several hundred students over 3 years in their end-of-year examinations. The end of year examination is a major, 2 hour assessment task, comprising a mix of 60-70 multiple choice and short answer questions that cover the entire range of topics taught in the course.

The answer from each student against each question was recorded and analysed. The analysis took the form of first identifying the proportion of students who had correctly answered the question. A low proportion of correct answers indicated the specific topics where most students were having difficulty. The spread of each answer set was also then analysed. Where the same mistake was being made by the majority of students answering that question (identified by a high proportion of incorrect answers against the same incorrect response) this was taken as an indication of a particular point of confusion. Where the mistakes ranged more or less equally across all incorrect answers this was also taken as an indication of students having difficulty with the topic, but without a particular point of confusion.

Approximately 25% of the questions were answered incorrectly by more than 50% of the student cohort. The most common problems were specific to timber frame, roof and staircase construction. There was also an over-riding problem with sizing and measurement issues, where students used metres in place of centimetres or millimetres and *vice versa*. Particular attention in the prototype Situation Engine has been given to timber details and sizing, but of course this information has also informed subsequent course content and delivery more generally.

A small reference group of users has been established to trial the prototype system and provide formal evaluation feedback on human factor and utility issues. The performance of the reference group in their end of year exam is also being assessed against a control group of other students in the same class who have had no exposure to the Situation Engine. All participants have remained anonymous to the course lecturer and examination assessor. The outcomes have informed a completely revised specification for the next round of prototype development.

The Situation Engine Prototype

The current implementation of the Situation Engine prototype seeks to replicate the existing model-building assessment task for the course. The same drawings have been used for a building constructed in the Situation Engine as for the model. In fact the Situation Engine contains a number of building models, and each might feature as part of the exercise. The setting for the exercise is a contained site of approximately 1,000m^2. The site is relatively flat, populated by a variety of trees and shrubs and bounded by natural features such as rock-faces. The layout of the site is traversed by a number of dirt tracks. There is a gated entry and the site contains a variety objects: temporary hoardings (corrugated iron, chain-link, etc.); construction plant (utility vehicles, diggers, etc.); specialised equipment (wheel-barrows, concrete-mixers, etc.); stockpiles of building materials (timber, bricks, concrete, etc.), part-constructed buildings and an existing warehouse structure. The vast majority of objects, from each individual tree branch to each partly constructed building, from wheel-barrows to vehicles, from fences to brick walls, can be variously broken, moved, driven, and/or entered. The weather is changeable and the sun rises and sets with the clock. Ground can be excavated, wind blows dust and crashes cause fires. The original site and the vast majority of these object behaviours were imported directly from existing objects available for free from the community of players and developers (so-called ‘modders’), and modified to suit our particular requirements. See Figure 4 for some example screen-grabs of the site at different points of the building construction process.

Figure 4: Screen grabs of the situation engine prototype at different stages of the construction.

Users interact with the Situation Engine by taking control of an avatar, or nominal construction worker. The situation is experienced in first-person mode, through the eyes of the avatar and by moving through the space as a person might. The avatar can walk, crawl, jump, climb, fall, grab, hit, drive, etc., but is otherwise constrained by the physicality of the body shape. Individual avatars are able to wander around and over the construction work, examining design details and following construction processes. They can, for example, observe how the work has been prepared, measure the distance between reinforcement saddles, test the capacity of the steel reinforcement under foot, check waste-pipe penetrations through the slab against best-practice guides, break away brickwork to reveal the construction details behind, etc. It is a multi-user environment, where each avatar is controlled by an individual student. Whatever one student/avatar does within or to the situation, other students/avatars see and experience those same actions and consequences at the same time, but from their own point of view.

The user is able to interact with the construction at any point, including when temporary bracing is still in place and as particular details between, say, bricks and timber and concrete are finished. At any stage the user is able to interact with the model and demolish parts of it to expose design and construction details. The extent of the demolition is dependent on the natural physics of whether the user employs, say, just their body-weight, a sledge-hammer or a truck. Users are also able to check the sizes and spacing of timber members against building codes, analyse the implications of loads on different structural configurations, check construction steps against project programmes, etc.

Discussion

The purpose of a Situation Engine is to provide for specific and managed practical building and construction experiences to be made available to students through advanced digital technologies. This is in response to the growing problems educators face when trying to provide authentic work experience directly. The situation is particularly critical for those who subscribe to a situated learning pedagogy: a particular orientation to teaching and learning that privileges practical experience of the work situation. Of course situated cognition is not without its critics (Vosniadou, 2007), and an approach that is exclusively sociocultural would undoubtedly ignore key cognitive aspects of learning and teaching. The focus of this project is on competence-based learning and assessment. It presumes that knowledge-based learning is a necessary precursor to skill-based learning. So, whilst we might never reach a definitive expression of competence in sociocultural terms alone, it seems equally inconceivable that competence is something that can ignore human dispositions and social constructs (Hager & Holland, 2006). The growing significance of competence in higher education requires that more urgent attention is given to how we might teach and assess skill-based learning in that sector.

A prototype Situation Engine has been developed and is in the process of being evaluated. The Situation Engine is designed to provide a particularly rich visual and behavioural context to the learning exercises required of the students. The environmental aspects incorporated are already very sophisticated and will be further enhanced as the system is revised and improved. A key element is the multi-user functionality, where the actual behaviour of other users is immediately incorporated into the user experience. Of course there are a multitude of limitations to the current system compared to an actual construction site. Some limitations are trivial to overcome, whilst others are unlikely ever to be resolved. For example, the current lack of appropriate construction safety attire on the avatars, such as hats and vests, is a relatively simple fix. The capacity to join materials or to begin with raw materials and construct any design is far more problematic. At the moment, construction processes are determined by a fixed outcome (design) and fixed schedule. Currently, students can only step through that prescribed process, selecting relevant materials in the correct order. This process will be much improved in the next round of modifications, to include options to order materials in advance and store them in selected locations on site.

The impetus for the development of the Situation Engine comes from a desire to improve student learning outcomes and assessment, particularly of the more competence-based outcomes. A formalised framework for the design and development, based on the ecology of resources approach, is proving significant in keeping the focus of the development and evaluation on learning improvement. The current approach, where the Situation Engine is evaluated as a complement to existing teaching resources, means the teaching focus remains on the key learning outcomes. For instance, it is inconclusive whether improved performance by students in the end of year examination is due to the Situation Engine *per se*, improved teaching resources in the course more generally, or simply more emphasis by the teacher on those aspects of the course students previously found confusing. Perhaps the only solid outcome that can be linked to the initial round of trials is the early realisation that the domestic construction design used for the model building exercise over several years is actually no larger than a standard garage. It was only when seen at relative life-size that the unnatural proportions of the model design became obvious!

Whilst the rich environmental modelling provided through the Situation Engine undoubtedly improves student learning and engagement, the improvement remains relatively marginal when compared to existing technology capabilities. The significant learning and assessment benefits are more likely to come when the system provides for more student decision-making and analysis. For the next round of development and evaluation it is proposed to use the prototype to test student understanding of related construction technology issues, such as safe work practices, material storage and handling considerations, site security, environmental protection, wet-weather hazards, noise pollution, etc. They will also be required to undertake more analytical exercises of existing building models to practice and demonstrate their higher-level diagnostic and forensic capabilities.

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