Simulation for Education in Construction and Construction Management

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Construction is a complex industry. It is particularly important to educate and train people in the procedures and management of the industry. Such training needs to be very broad in order to provide maximum benefit. It also needs to facilitate faster and more reliable learning than the traditional 'learning on the job' which used to be the way of initiating fresh graduates to construction management.

Traditional education and training can only improve some aspects, but simulation has been introduced to broaden the spectrum of and improve the effectiveness of learning to cope with more complex issues that face engineers in the industry. Typically simulations are computer-based and designed to tackle the management of technical aspects of construction. The authors have many years of experience of running courses at various levels using such simulations. However, this type of simulation can lead to a false understanding of the effectiveness of the methods being considered. For example, a simulation designed to 'teach' planning and control will almost certainly neglect the human influence or model it in a simplistic manner. The learner is then likely to acquire a biased or partial view of the effectiveness of the techniques and not appreciate actions that are necessary to use them in practice.

This paper discusses how a computer-based simulation has been used in practice in a number of institutions around the world (U.K., Netherlands, Malaysia, Australia and New Zealand) using simulation. It is based on many years of experience of developing and using IT and non-IT based simulations and examples currently being used are provided to illustrate the arguments. It concludes by suggesting areas for future IT-based development of simulations for education and training.

1. Introduction

It is now widely accepted internationally that the education of engineers must be much more than a technical education. (IPENZ, 2011). A graduate must be equipped for their career as a professional engineer, with all of the attributes that this infers. The Washington Accord (1989), an international agreement for mutual recognition of engineering qualifications acknowledges this. The Accord highlights the need for developing attributes ranging from in depth technical knowledge to the more qualitative management skills, understanding of engineers' responsibilities and the ability to communicate effectively.

All countries whose professional engineering bodies are signatories to the Washington Accord have an accreditation process for university courses that checks for the appropriate inclusion of all elements of a graduate's education. Engineers' academic technical training is completed, in the main by a degree qualification. These degrees have traditionally focused on the technical, more quantitative aspects of engineering.

Less well catered for are the more qualitative aspects of an engineer's learning – the management of resources, processes, procedures, communication, sustainability, people management. For many institutions these areas have been presented using the same techniques as structures, geotechnical and water engineering subjects but this has not been followed through with the same application of theory experience in the way that design is used to give experience in use and application of technical subjects (e.g. structural analysis).

Qualitative subjects (the management of resources, processes, procedures, communication, sustainability, people management etc) need reinforcement by use just as much as technical subjects.

This paper sets out how this has been done in a number of institutions around the world (U.K., Netherlands, Malaysia, Australia and New Zealand) using simulation.

2. Simulation as a Tool in Engineering Education

During the development of engineering competencies and abilities it is particularly important to educate and train students, graduates and junior engineers in the procedures and management of the industry. Such training needs to very broad in order to provide maximum benefit. It also needs to be more rapid than the traditional 'learning on the job' which was the traditional approach to 'management'.

Management-type simulation games have become a commonplace learning tool at all levels of instruction from early school teaching to postgraduate education and industrial training. They are an ideal mechanism for the transfer of knowledge of managing complex systems such as companies, projects and industrial processes without risk (Gilgeous & D'Cruz, 1996; Prensky, 2001).

Simulation is a natural concept for inclusion in engineering education. It removes the costs and risks of the real world whilst enabling people to gain many of the experiences. Therefore, if people can really learn efficiently by experience, simulation should be used. There are aspects of engineering which require experience to really understand and these should use simulation as a teaching / learning tool.

Over the last fifteen years the technology available to games designers has changed beyond recognition. However, it is not solely the increased use of technology that makes the game successful in helping students achieve the desired learning outcome. The purpose of simulation is to create a learning environment that mirrors reality so as to allow the player to develop skills that can be applied in the real world. If the simulation does not appear to act and respond as the real world then the learning will be deficient. Also if the players lose confidence in the reality of what they are doing, and the exercise becomes a game like 'Monopoly', then the value of using the simulation for real learning is lost. This creation of the appearance of reality is called verisimilitude.

Often IT based simulation packages/programs (often referred to as games) are used to create verisimilitude because computational power and speed allows the trainer to concentrate on facilitating the student-engineers' learning. However this can sometimes give a false sense of achievement and the simulation package becomes no more than another computer game. This paper, therefore, has three functions:

1. To demonstrate the types of situations that can be successfully simulated for e-learning.

2. To discusses how to create a simulation exercise that has verisimilitude, sufficient to deliver learning outcomes that develop appropriate graduate attributes

3. To review the success of simulation in achieving appropriate learning outcomes

The simulations presented have been used in the U.K., Netherlands, Malaysia, Australia and New Zealand and are based on construction projects which the players have to manage. The objectives, structures, features and usage of these games are demonstrated by giving examples of how the games are used, the lessons that have been learnt and the most significant and important features.

All of these features are interlinked and interdependent. The simulations developed for the management of construction are used here to demonstrate of how all the parts fit, interact and work together.

3. Experiences using Simulation as the Principle Learning Tool

Simulation can be used effectively for students in university and in industry based training for engineers with some years of experience so the players of the 'games' are able to learn and build on their prior experience. The focus of any simulation should be the learning outcomes. The expected learning outcomes and how they were achieved for specific fields of management and construction management are presented here to illustrate and demonstrate this concept. These observations are based on 40 years of using simulations that have ranged from totally IT based to none.

The simulation games and software that have been developed and that are used here as illustrations are:

a) Muck Game (Dam game) – construction of 30m earth and rock dam,
b) Canal Game – construction of 7km of clay lined canal.
c) IESSG BizSim – A generic business start up simulation (aimed at high-tech SMEs)

Each game has a similar interface and method of working but the scale and complexity of each project is different. Games focus on the planning and control of projects and business with a mix of interactive resources.

a) The Dam and Canal games were designed to be used to teach players about the control of construction. Each has its own challenges and learning focuses but essentially they allow the students to develop skills in planning, monitoring and controlling construction resources of equipment, personnel, time and money

Players are required to develop a plan for completing the project, select appropriate resources, supervision and training and then run the project. They must take appropriate control action, including re-planning, in response to results from the simulation.

An 'Umpire' package that monitors, tracks and reports student performances is also described along with the reasons for its development, its role in teaching and student monitoring

b) The game called BizSim was used to simulate the student's own business plans. This allowed students to 'invent' their own company, to produce a business plan for it and to run it through the first two years of its life.

BizSim consists of two main elements; the Creator tool and the Simulation Game itself. Both these elements draw on a common data model that represents the simulated business environment. The creator tool is used to generate bespoke simulation environments to reflect the start-up companies proposed by the student business plans and the business environment in which they will operate. Once the simulations have been created and extensively tested they are ready to be used by the students who run the Simulation Game.

3.1 The Dam Game – developing engineers' management skills

Dam game will be used to illustrate the essential structure and typical features of a successful simulation. For the sake of clarity the student or engineers who are involved in 'playing' the simulation game are referred to as players and the teacher/mentor/controller who is running the exercise is the umpire.

The game, described in this paper, was designed to teach players about the control of construction – not the construction of earth dams but rather the general and generic principles of construction management, although actual fill calculations, toi be done by players increased the sense of reality of the game.

There were several detailed objectives to be considered in the design of the game. These can be summarised as

- To provide a 'realistic' model of a construction project which will react in physical and financial terms to the decisions made and actions taken by the player
- To provide reports as might be expected on a real project
- To include uncertainty but to control it in such a manner as not to hide the effects of control actions
- The game should, if possible, be suitable for use by both undergraduates and practicing engineers.

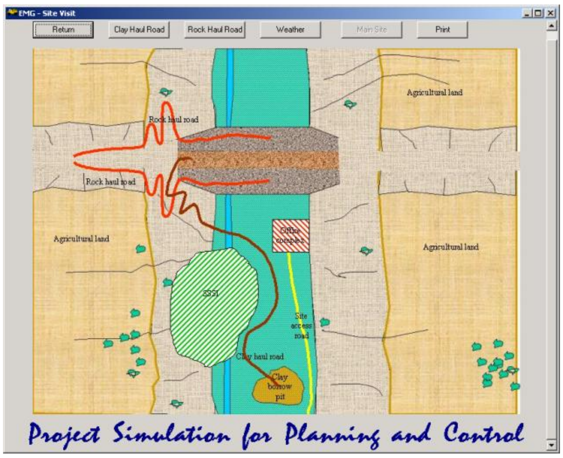

Figure 1: The Dam Game project

One of the main aspects of a project based management game is the project which is modelled. The project must be simple enough to be contained within a game and appreciated by the players but complicated enough to provide a realistic challenge to them. It would be pointless to consider using a project which could not be realistically modelled with the computer system available and it would be counter-productive in terms of motivation if the model were either too complicated or too simple for the players.

In terms of complexity, it is also important that the project must be complex enough to illustrate the intended points whilst not being so complicated that the players will be unable to understand the lessons inherent in it. There will also invariably be limited time to play the game, either because of the limitations imposed by the course or because the players are unwilling to devote any more time to it. This will limit the complexity of the project. Use of IT to run the simulation allows reality to be balanced with complexity of operation.

Figure 1, shows a general sketch of the project generated by the IT simulation package. The project is based on one that was developed for a text-based game a number of years ago and used for undergraduate teaching for a number of years.

The dam is rock-fill with a clay core. The finished dam is 30m high and 300m wide at the top. The player takes the part of the contractor's project manager and is responsible for the planning, resource selection and use, the control and the reporting to the company management. Resources are required to excavate, transport and place the rock and clay and to maintain the haul roads.

The information for the project must be complete in all relevant detail, sufficient to create the appearance of reality but not too complex to cloud the teaching objectives. If the project does not appear ‘real’ to the player (the verisimilitude) then the desired learning outcomes will be jeopardised.

The development of the data for a new project is almost as large a task as the development of the game itself because it is, to a large extent, the project which gives the game its character and which ensures that the game can fulfil the objectives set for it.

3.2 Structure and Main Features of the Game

There are two roles in this game, the game umpire and the player.

The game umpire sets up the game and acts as the contractor’s head office whilst the player takes the role of the project manager for the contractor. The project is for all the earthmoving needed for dam construction and the contractor has to provide all resources (equipment) necessary. The player is made responsible for the performance of the project and reports to the umpire, in the role of head office, as and when specified.

The resources to be managed are those required to carry out the work of excavation, transport and placing of the rock and the clay. The site is affected by the weather, particularly the rainfall, and the resources are subject to breakdowns.

Costs are incurred by the contractor for the resources employed and for overheads. There are also liquidated damages payments for exceeding the 40-week allowed duration. Payment is made based on completed work. Retention of 10% is made on all payments. The contractor estimates costs per cubic metre of material and plans both the physical and financial progress of the project.

Since the umpire can vary all external variables (rainfall patterns, breakdown rates etc.) the project can be made to behave very differently for players of different levels of experience.

3.3 The User Interface

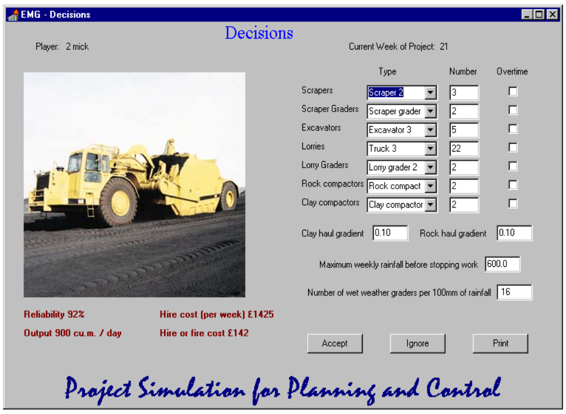

Figure 2: Screen for the selection of equipment

Figure 3: Player performance graph

The interface was designed to make use of the computer power and to develop and maintain the players’ motivation and to present the players with reports which might be expected on a real project.

A player can either choose to work by selecting the buttons or by clicking on a relevant part of the screen. A typical screen for the selection of equipment is shown in figure 2.

There is considerable assistance and information available to the player within the game, like average rain patterns, specific information on available equipment etc.

3.4 The Umpire

Throughout game play the teacher/umpire can monitor players' progress using a specifically designed IT package. This allows the umpire to check the progress and performance players throughout the simulation exercise using recorded player input, performance records and messages. The information can be used to explain developments to students, be a basis for discussion of methods and techniques of planning, monitoring or control, allow the umpire to identify struggling players or to compare the performance of players. Custom graph specification allows the umpire to define type and content of graphs. Figure 3 is an example of the output.

It is essential for the game supervisor to have a means of measuring the performance of the players throughout the simulation. Not only does this facilitate learning and discussion, it also provides evidence of the learning effects of the game. However this information service to the umpire must be carefully constructed so as not to destroy the operating environment (verisimilitude) for the game players

The more the game supervisor can monitor the play environment the greater the opportunity to exploit the players' performance to reinforce the student/engineer learning.

3.5 Monitoring and Communication within the Dam Game

In addition to their use of the games at the weekly clinic sessions, students are able to play the games at any time. In order to ensure that students are able to raise any significant learning issues or technical issues regarding the simulation games it is crucial that students can communicate effectively with teaching staff.

It is also important for staff to be able to reply easily to the students and be able to message all students in-game with any important announcements or changes to the games or the simulated project data. Both of these facilities are provided by the umpire's IT based package.

4. Incorporating IT in Simulation Games for Construction Management

Key points for development of IT based simulation games for construction management

- Learning objectives of the module must be established first.
- Chose a scenario that is suited to these outcomes and that can be simulated with a high degree of realism (verisimilitude).
- Craft the package optimizing the IT support. Balance reality with complexity. It must allow monitoring of student performance and their leaning while at the same time maintaining the verisimilitude of the exercise.
- Develop the software such that it allows monitoring of students' achievement of the learning objectives.
- Check effectiveness of the package when used in an appropriate learning environment and be prepared to change.

Simulation is a very useful tool if used in a way that recreates a realistic environment in which models complex management situations. Such is the level of complexity of the construction industry that this is best done by incorporating IT support that allows the users of the simulation to achieve appropriate learning outcomes.

5. Evaluating the Success of Simulation as a Learning Tool

Several methods (observations, student achievement of assessment tasks, and student questionnaires) were used during the evaluation process to gather information about the effectiveness of simulations in developing students' knowledge and professional practices.

Students' learning outcomes from simulation exercises were tightly linked to the generic skill statements for their overall engineering course, these included:

- demonstrating and articulating an understanding of professional engineering, its structure, workings and relationships with society;
- applying scientific/mathematical and technical theory to engineering problems;
- identifying, defining and providing solutions to engineering problems;
- producing engineering style reports;
- using engineering judgement in both quantification and elementary modelling;
- structuring engineering problems into a sequence comprising identification, formulation, solution and impact;
- demonstrating a range of effective engineering communication skills;
- collaborating effectively in, and identifying the working-benefits of, a multidisciplinary and multi-cultural teams; and
- showing an appreciation of the role and responsibilities of professional engineers
- experiencing the complexity of a project, not all situations can be planned for beforehand and random events can greatly change the project outcome

6. Major Teaching and Learning Implications of using Simulation

Students working with the simulation

It has become clear that the simulation does not replace the teaching of essential information required for project management; it is a learning tool which must be used in conjunction with formative and iterative teaching strategies. Once students can master the mechanics of engaging in the simulation, their learning from the simulation will be heightened.

Students working with uncertainty and making informed judgements

Working with large amounts of uncertain and often unreliable data such as is the case in real engineering situations was a challenge to many students. This issue also is tied to providing more information to students about how to move from theories learnt using problem specific accurate data (e.g. cost calculations) to the way in which they will have to apply these theories in real world complex multi-variable situations.

Students working in groups

The simulation evaluation clearly demonstrated that often students had little prior experience in working in groups as part of a learning experience. They were still keen to know about their individual performance within their group. This can be accommodated without prejudicing the important attribute of being able to work in and for a team.

Development of professional attitudes and attributes

One of the most challenging parts aspects of this type of learning experience is for the students to translate their learnt skills from the specific environment into general strategies and approaches that they can apply and develop when they next encounter them in the real wider world of engineering e.g. how do they develop what they have learnt about team work, project control, strategies to control production etc. Forcing them to report to 'head office' (orally and in writing) and make recommendations makes them reflect on and articulate their learning.

Reviewing students' understanding and attitudes to the targeted generic skills before, during and after using the simulation demonstrates to them and their teachers how well the simulation is achieving the learning objectives.

7. The Success of Simulation as a Learning Tool for Engineers

Simulation exercises have been used by the authors to develop professional engineering skills in a wide range of countries and teaching environments. Evaluation of learning outcomes is essential. Methods used can be any that allow objective evaluation of the extent to which the learning outcomes have been achieved.

The success of simulation in achieving targeted learning outcomes has been assessed using a variety of methods. These indicate that a higher achievement of management orientated learning outcomes have been achieved than is possible using conventional teaching methods.

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