

Simulation for education in construction and construction management - IT or not IT

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Abstract

Construction is a complex industry and there is a general perception that it is uncertain, unsafe and inefficient. In order to improve the industry, the training of engineers needs to be very broad. It also needs to be more rapid than the traditional ‘learning on the job’ which used to occur. Traditional education and training can only improve some aspects and simulation has been introduced to broaden the spectrum of and improve the effectiveness.

This paper suggests what aspects of construction and construction management can be usefully simulated using IT and which cannot. It first discusses the pros and cons of using simulation to train engineers in the non-technical areas that are now essential attributes of engineers. It then reviews simulation packages that have been used in various situations and the learning objectives of each. The use of simulation games as the principle learning tool for specific learning outcomes is then discussed, exploring the difficulties and challenges as well as the benefits gained from using IT systems as a core part of simulation packages. It concludes by suggesting areas for future IT-based development of simulations for education and training.

Keywords: simulation, learning, game, construction

1 Using simulation to train engineers

Engineers’ academic technical training is completed, in the main by a degree qualification. Less well catered for are the more qualitative aspects of an engineer’s learning – the management of resources, processes, procedures, communication, sustainability, people management. 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 be more rapid than the traditional ‘learning on the job’ which used to occur.

Management-type simulation games are now 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 always 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 it exercises becomes a game like Monopoly or flight simulator, 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 two main functions. First to demonstrate the types of situations that can be successfully simulated for e-learning. Second it discusses how to create a simulation game that has verisimilitude, sufficient to present learning opportunities that will be valuable in the real world of construction.

The simulations presented have been used in the UK, the Netherlands and Australia 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.

2 Use of simulation games as the principle learning tool for specific learning outcomes

Simulation can be used effectively for students in university and in industry based training for engineers with some years of experience provided 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 idea of using a computer simulation or management game to help students learn about complex issues is not new. Gilgeous and D'Cruz (1996) describe simulations stretching back over many years. The use of management games for teaching and learning about project planning and control is also not new and was described by Scott and Cullingford in 1973. Further, Au and Parti (1969) described the use of a game using a project with a significant amount of earthmoving as a basis. Not all games have to be complex and computer based and Tommelein et al. (1999) describe one which can be run either manually or on a computer to illustrate the interaction of parties on a project. More recently, the Internet has featured with games as part of the learning environment (Sawhney et al., 2001; Mawdesley et al, 2007).

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

- a. Muck Game – construction of 30m earth and rock dam,
- b. Canal Game – construction of 7km of clay lined canal.
- c. IESSG BizSim – A generic business startup 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.

Software used to manage and run the simulation games is described. An 'Umpire' package that monitors, tracks and reports student performance 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 Learning Outcomes for Simulations

Learning outcomes for engineering education are quite varied and often specified on a national level (see for example, QAA). Not all of these outcomes can be achieved using simulation and it is important not to be over ambitious in setting the expected learning outcomes. The learning outcomes can be quite generic such as:

Communication skills

Negotiation skills

Or quite specific such as:

The ability to use earned value analysis to monitor and control a construction project

The ability to produce a realistic plan for a construction project

The ability to manage resources working in teams.

4 The Dam Game: a simulation used to develop 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 be used to teach players about the control of construction – not the construction of earth dams but rather the general and generic principles of construction management.

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.

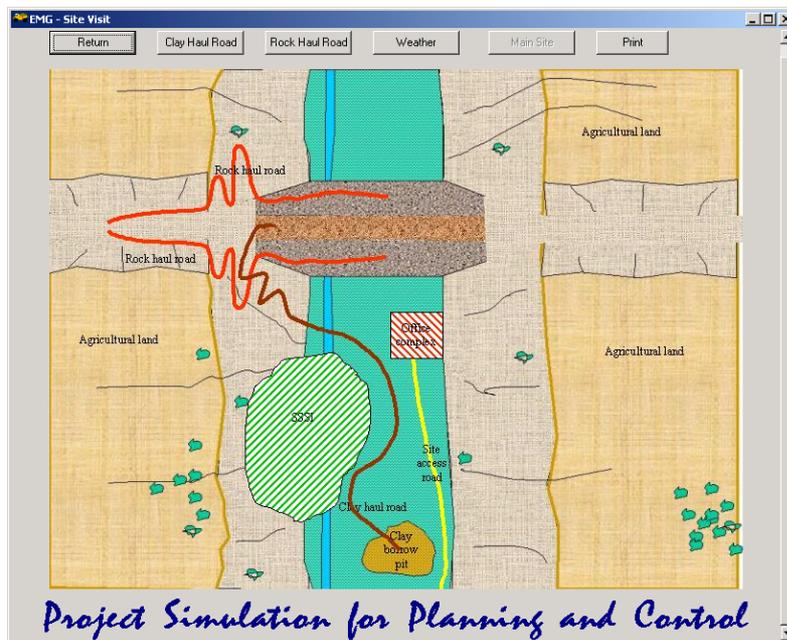


Figure 1: The Dam Game project.

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.

4.1 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.

4.2 The user interface

The game is written in Pascal and was developed in the Borland Delphi IDE. 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.

It uses a WIMP interface together with pictures, text based reports, graphs of physical and financial progress and control charts, video clips, animation, web access, PowerPoint presentations and notes provided in HTML format.



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.

4.3 *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.

4.4 *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.

5 Creating an appropriate simulated environment for learning

The IT based simulation has to be able to support the teacher/umpire and free them from administration and calculation so that they can concentrate on facilitating learning. In addition the simulation must be run in an environment that suits the prior learning, knowledge and experience of the players.

The games described here have been typically run with varying levels of supervision during play. At one extreme, they run as a module which is based totally around the use of the simulation games, without lectures, apart from a brief introduction, but has clinics at which the players can discuss any issue. This has worked best at postgraduate level with players with industry experience who are developing applied management skills. At the other extreme (with 'junior' students) the games are run in conjunction with supporting lectures and a high level of supervision and direction.

The amount of supervision and IT support required by a game depends on:

The game itself and its complexity

The level of prior knowledge of the players

The learning outcomes which the game addresses

The amount of supervision which can be provided will depend on:

The number of players

The skill and knowledge of the staff

The experience of the staff with the game

These considerations need to be balanced and a workable environment developed, often determined as experience is built up.

5.1 Observations on the simulated environment

The development of e-learning based simulation packages is expensive in time, cost and resources. Careful and methodical building and authentication of these packages is therefore essential.

Creating an appropriate environment that achieves the desired learning outcomes is paramount. To do this requires customisation of the simulation game that allows the 'payers' to feel that they are working as real people, making real decisions in an environment that responds to their decisions in a realistic way.

It is essential to authenticate the simulation exercise by checking the learning outcomes. Such exercises reveal weaknesses but also give a deeper insight into the learning achievements of the players and how even more success can be achieved with relatively minor changes to the simulation or the way in which it is presented.

5.2 Lessons learned about developing and using games

Experience of how to use games successfully had been built up over a number of years using several games. The lessons learnt have typically been incorporated in the next cycle of game use. This section presents some these experiences, the events that brought them to light and how they were addressed. The areas covered are;

Setting learning outcomes consistent with player experience

Effectiveness of control and learning

Importance of Student Monitoring In E-Learning Exercises

5.3 Setting learning outcomes consistent with player experience

The games have been run as part of undergraduate courses. They have also been used by an industry organisation as part of its graduate recruitment and selection procedure. Lessons were learnt about player experience pre-game, existing professional knowledge

Undergraduate course use: This was part of a generally lecture based course. Participants worked in small groups (2,3 or 4). Groups were both necessary, because of the large number in the class, and beneficial because they encouraged discussion and peer learning.

Early career/in service training: Training in-company focuses on the particular needs and operating policies of the organisation and performance needs to be assessed using the organisation's benchmarks.

Use in Company recruitment: One major 'construction to services' company used the game as part of its recruitment process. It invited students interested in joining them to attend a course run one evening per week over four weeks.

Modest learning objectives are essential at undergraduate level. Achievements are greatest in understanding basic professional practices and procedures. At industrial level higher levels of performance can be expected and professional management skills could be developed without costly mistakes in real practice.

5.4 Effectiveness of control and learning

It is important to attempt to monitor the students progress as the game proceeds not only to assess its effectiveness of learning but to 'rescue' those who are floundering. This needs to be done without apparent 'divine' intervention by an external force who 'happens to notice' players' progress or

difficulties. It must also be an easy to check measure that the game supervisor can check quickly without excessive computation.

5.5 *Student performance and its relationship to learning outcomes*

The monitoring and assessment of student performance and learning is an essential element of successful use of simulation packages. In any exercises that simulate construction projects of any size IT support is essential for management of information so as to maintain the reality of the complex information flow on a real construction site. If this is properly taken care of then the umpire/tutor can concentrate on monitoring player performance and learning.

The success of simulation games in achieving their stated learning outcomes has been assessed. These include survey methods, monitored student performance (during simulation exercises and in assessment) and student feedback. The surveys indicate a higher achievement of management orientated learning outcomes than was achieved using conventional teaching methods.

Evaluation of learning outcomes is essential. Methods used can be any that allow objective evaluation of the degree to which the learning outcomes have been achieved.

6 Incorporating IT in simulation games for construction management

The development of mass market games has raised the expectation of students when it comes to using games for teaching and learning. However, the reality is that no body can, as yet, afford to develop teaching and learning games with the same degree of user interaction as the 'best' mass market games. It is also impossible, as yet, to model the construction processes including the human interaction of large projects in sufficient detail to warrant this. However, computer-based games can make a significant contribution to teaching and learning of construction.

Following the development of the games described in this paper, the authors recommend that the key points for development of IT based simulation games for construction management are:

The learning objectives of the module must be established first.

Choose a scenario that is suited to these outcomes and that can be simulated with a (sufficiently) 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.

7 Conclusion

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.

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