Developing Knowledge for Real World Problem Scenarios Using 3D Gaming Technology within a Problem-Based Learning Framework

Michael Garrett  
Edith Cowan University  
michaelgarrett@iinet.net.au

Dr. Mark McMahon  
Edith Cowan University  
m.mcmahon@ecu.edu.au

Abstract. Problem-based learning is an instructional strategy that emphasizes the accumulation and development of knowledge via an active and experiential based approach to solving problems. This pedagogical framework can be instantiated using First Person Shooter gaming technology to provide users with the ability to control their learning experience within a dynamic, responsive, and visually rich three-dimensional virtual environment. In this manner, real world problem-solving scenarios can be represented within a computer simulated environment for training purposes, with a view towards developing knowledge and skills that are applicable to the real world problem-solving scenarios being modelled. This type of training environment can be utilized effectively when training within the corresponding real world space may not be safe, practical, or economically feasible.

To this end, a conceptual framework has been developed in order to inform the design of 3D simulation environments based on FPS gaming technology within a problem-based learning pedagogy. This framework identifies a series of design factors relative to the user, the problem-solving task, and the 3D simulation environment that are proposed as being necessary in order to guide the learning process and facilitate the transfer of knowledge. This paper will present a simulation environment design according to this conceptual framework for a problem-solving scenario within the context of an underground mine emergency evacuation. This problem-solving scenario will be modelled with reference to Dominion Mining's Challenger mining operation located in South Australia.

1. INTRODUCTION

Computer-generated three-dimensional (3D) simulation environments allow users to experience real, recreated, abstract, or imaginary environments that may be of impractical size, infeasible distance, prohibitive cost, or too significant a hazard to experience in person (Baylis, 2000). These virtual worlds allow users to perform actions that may not be possible, practical, safe, or ethical to conduct in the real world system that is being modelled. As a result, 3D simulation environments provide safe and effective tools for education and training, enabling the development of knowledge and skills for use in real world environments. Most importantly, the virtual environment can authentically represent the aspects of the real world to enhance learning transfer (Brown, Collins, & Duguid, 1989; Dobson et al., 2001).

The technical development of 3D environments has been heavily influenced by innovations within the gaming industry, where high consumer demand has driven rapid advancements in associated hardware and software technologies. This is particularly evident with regard to First Person Shooter (FPS) games, where the player is provided with a first person perspective of a three dimensional environment. FPS games are typically characterised as being on the cutting edge of gaming technology in terms of visual fidelity and performance, and have amongst the highest of expectations placed upon them by the gaming public. The abilities of 3D gaming technologies, in particular the game engines used to power FPS games, have not gone unnoticed, with proponents of computer assisted learning recognizing the potential of these technologies to function as simulation environments. This has given rise to the serious games movement, which focuses on the application of gaming technologies and concepts for simulation and learning purposes. FPS game engines have been successfully used to this end in fields such as architecture, military, mining, and safety (Bonk & Dennen, 2005; Malhorta, 2002; G. Mantovani, Gamberini, Martinelli, & Varotto, 2001; Orr, Filigenzi, & Ruff, 2003).

In order to facilitate learning in a simulation environment, the environment must go beyond modelling the system to provide goals and guidance for the end user (de Jong et al., 1998; Withers, 2005). One such framework that is consistent with the experiential and user-focused nature of 3D simulation environments is that of problem-based learning. The process of solving problems and the subsequent knowledge that is acquired supports the generation of contextual knowledge for use in future applications. Problem-based learning promotes active,
transferable learning whereby learners use the task to develop a strategic model that can go beyond the specific problem to solve future problems (Barrows & Tamblyn, 1980).

This paper provides a conceptual framework for the design of problem-based learning using 3D technologies. The framework articulates criteria that need to be considered when designing effective problem scenarios within 3D simulations. This is then instantiated within the context of a 3D mining simulation for Occupational Health and Safety to demonstrate how considerations relating to the user, technology, and the problem-solving task can be applied within a training context.

2. PROBLEM-BASED LEARNING WITHIN A 3D SIMULATION ENVIRONMENT

The framework presented in Figure 1 was derived from a review of the literature that explored the interplay between the nature of the problem-solving task, the affordances and limitations of 3D simulation environments, and the characteristics of the user.

![Figure 1: A conceptual framework detailing the factors that facilitate problem-based learning within a 3D simulation environment based on FPS gaming technology](image)

To a certain extent, the user characteristics can only be defined by the context of learning. Nevertheless, it is a necessary consideration when contemplating the nature of the problem-solving task in terms of the level of structure, complexity, and domain specificity, and the extent to which it matches learners' existing problem-solving skills and prior knowledge. Similarly, the characteristics of the environment must be considered in terms of the level of control that is afforded the user. With the ultimate goal being transfer of learning to real world problems, it is therefore necessary to explore the nature of the task, how the interaction with the user promotes transfer, and the capacity of the environment to support that.

2.1 Problem-based Learning

Problem-based learning is an approach to learning that is situated in problem-solving experience and consistent with experiential-based learning (Hmelo-Silver, 2004). Two fundamental postulates drive problem-based learning; that learning through problem solving is more effective in the creation of bodies of knowledge usable in the future, and that problem-solving skills are more important than memory skills (Barrows & Tamblyn, 1980). Problem-based learning uses problems as the stimulus and focus for student activity and differs from other instructional methods in that it begins with problems rather than with the exposition of disciplinary knowledge (Boud & Feletti, 1997). Problem-solving, the process of which is influenced by both factors internal to the problem solver, in terms of their existing knowledge, skills, and experience, and external in terms of the variable characteristics and representation of the problem (Jonassen, 2000; Lee, 2004; Newell & Simon, 1972; Smith, 1988; Zhang, 1991), is thus a key component in problem-based learning.

Problem-based learning is successful only if the scenarios that learners engage in are of high quality (D. F. Wood, 2003). These scenarios need to be provided in a format that allows the learner to challenge and develop their reasoning skills and stimulate their self-directed study (Barrows & Tamblyn, 1980). Problem-based learning scenarios should also facilitate the learner's ability to evaluate their skills and knowledge in working with the problem (Barrows & Tamblyn, 1980; Hmelo-Silver, 2004). The design variables to be considered in this regard thus relate to the format and presentation of the problem and the manner in which the learning process is directed and controlled (Arts, Gijswommen, & Segers, 2002; Barrows, 1986).

2.2 Learning Transfer with Computer Simulations

A simulation represents a real world system to foster the transfer of knowledge and to develop conclusions that provide insight into the behaviour of the real world system being modelled (McHaney, 1991; Towne, 1995). The success of a simulation is often measured by the degree of knowledge transfer and is only of value if the skills addressed and improved upon in the simulation environment are required in the operational environment that is being modelled (A. L. Alexander, Brunyee, Sidman, & Weil, 2005). Representing the system and its underlying behaviour facilitates this objective, with the assumption being that a faithful representation will encourage knowledge transfer between the simulation environment and the real world system.

This assumption is consistent with Brown, Collins, and Duguid's (1989) theory of situated cognition which asserts that knowledge is situated within the activity, context and culture in which it is developed and used. Such activity promotes cognition through the deliberate use of the social and physical context of the environment (Brown et al., 1989). The communities of practice that evolve through the interplay between experience and ability in situated cognition ensure outcomes that are culturally appropriate.
Simply modelling an authentic environment however is not enough to ensure learning without an instructional framework to effectively support and guide learning (van Rosmalen, 1994; Tait, 1994; Withers, 2005). By utilizing a problem-based learning framework in this regard, authentic activity is the basis for encouraging the reflection necessary to ensure that the developed skills can be applied to future problem scenarios in the real world. Simulations and problem-based learning share common goals in that they are both directed towards the application of knowledge and concepts to new situations. Thus, simulation environments can be used to enhance the potential for transfer inherent in problem-based learning.

2.3 3D Environments
Computer-generated 3D environments based on FPS game engines are an appropriate means for simulating real world environments based on their ability to represent three dimensional spaces at a high visual quality while maintaining a frame rate that allows the user fluid control of the virtual environment. Simulation environments of this nature utilise Euclidean geometry to describe the objects within them, and as such, can be used to construct scale representations of real world spaces, preserving dimensions, perspective, and relative distances to scale. Furthermore, the potential for high visual fidelity inherent in this type of environment can be used to depict a realistic virtual space where the behaviour of objects and their subsequent relationships with each other and the user can be represented appropriately, whilst also providing the user with a sense of presence and immersion (Germanchis, Cartwright, & Pettit, 2005; Sadowski & K Stanney, 2002; Shiratuddin & Thabet, 2002).

Given these capabilities, 3D environments based on FPS gaming technology are well suited to the representation of real world tasks that may involve movement and orientation, complex object manipulation, or decision making in a three dimensional space (Munro et al., 2002). Furthermore, the scripting languages and other programmable constructs inherent in FPS game engines provide the ability to develop 3D simulation environments within a problem-based learning framework, where assessment, feedback, control and guidance of the learning process, and appropriate learning resources can be provided in order to structure and facilitate instruction.

3 CONTEXT OF THE SIMULATION DESIGN
Dominion Mining's Challenger Gold Mine has identified the potential for a computer-generated simulation environment of their underground mining facility to be utilized as part of their emergency training procedures for underground fire scenarios. Dominion's existing procedures direct personnel to locate one of several refuge chambers that are located throughout the mine in the event of a fire, the process of which is detailed during the induction training that all personnel are required to complete as a condition of employment. These refuge chambers can be reached by traversing the main decline, which is the primary mining shaft, or via escape rises, which are 20 metre vertical ladders that link each level of the mine. The refuge chambers provide a safe haven for personnel while they await rescue and are self contained, with their own battery power supply and oxygen cylinders independent to the power and air that is provided from the surface.

A computer simulation of the underground mine has been proposed in order to train personnel to locate an appropriate refuge chamber given their location within the mine and the most appropriate route to take through the mine in order to reach it during the event of a simulated underground fire. This decision making process is contingent on factors that relate to:

- the availability of breathable air;
- the duration of the oxygen supply in a self rescuer;
- the physical exertion and subsequent demands on the self rescuer oxygen supply that are required to reach a given refuge chamber;
- the location and severity of any potential hazards, and;
- visibility factors that may arise due to power outages or smoke from a fire.

Thus, locating an appropriate refuge chamber constitutes a problem-solving scenario whereby personnel must reflect on the best course of action based on the conditions of the environment and their own capabilities. This problem-solving scenario will be developed within the following conditions, with the behavioural objective being successful performance of an evacuation procedure to a refuge chamber:

- Primary goal during an emergency evacuation scenario;
- Locations of refuge chambers and escape rises within the mine;
- Layout and structure of the mine, including the visual cues that can assist navigation;
- Procedure for emergency evacuation;
- Function of escape rises and appropriate usage;
- Function and capabilities of the self rescuer and cap lamp;
- Environmental conditions that can affect the ability to reach a refuge chamber;

4 DESIGN OF A CORRESPONDING SIMULATION ENVIRONMENT
Based on information provided during a situation analysis of the emergency evacuation scenario at Challenger, a design for a corresponding simulation environment was derived with reference to the conceptual framework depicted in Figure 1.

4.1 The User
As a result of Dominion's mandatory induction training program, a common level of knowledge was identified amongst personnel. Trainees had knowledge of:

- The spatial configuration of the mining
environment, including knowledge of the layout of the mine and the locations of refuge chambers;

- The mining equipment that may be required during an emergency evacuation, including the self rescuer, and the helmet lamp;
- The environmental conditions and potential hazards within the mine that may affect the ability to reach a refuge chamber safely, and;
- The emergency evacuation procedure advocated by Dominion in the event of a fire within the underground mine;

Given the variance in experience amongst personnel at Challenger, it was determined that the problem-solving scenario should be separated into three problem-solving instances which become progressively more challenging in order to maintain motivation amongst personnel who were more familiar with the Challenger mining environment. By separating the problem-solving scenario in this manner, shorter but more numerous cases could be used to provide a greater number of examples with the aim of enhancing problem-solving when new problems were encountered (Charlin et al., 1998).

4.2 The Problem-solving Task
Maintaining the concept of separating the problem-solving scenario into a series of separate problem-solving instances in order to motivate the more experienced personnel at Challenger, the problem-solving scenario will be implemented such that each successive instance becomes more ill-structured as progress is made. Each problem-solving instance will provide the user with progressively less initial information explicitly, thereby increasing the level of uncertainty associated with each problem-solving instance. The three problem-solving instances will also become successively more complex as the extent of the environmental conditions within the virtual mine and their potential impact on reaching a refuge chamber become more severe.

The situatedness of the problem-solving scenario within the simulation environment will be enhanced via the provision of user abilities that are intended to replicate the activities that are possible within the Challenger mine during an emergency evacuation. This situatedness will also be evident in the accurate depiction of the spatial characteristics of the environment and the use of authentic visual cues and real-world conditions. Similarly, the culture of the real world mining environment at Challenger will be conveyed via evidence of a human presence within the virtual mining environment, utilising audio cues for vehicle radio communications and depicting mining vehicles that might be expected to be found within the mining environment. The information cues provided through these authentic mechanisms will also be appropriate and consistent with the type of information that would be inherent in the real world scenario, and with the information provided in prior training, such as their initial position within the mine, and the location of the nearest refuge chamber for some of the problem-solving instances.

The instructional sequence itself will be depicted within a 3D virtual representation of the Challenger mining environment. A combination of sequential and simultaneous information will be presented to the user at the onset of the problem-solving scenario in order to provide the user with initial information pertaining to the problem-solving scenario as well as establish the conditions within the environment around them. A number of aspects of the problem-solving scenario were also identified as requiring high fidelity representation within the simulation environment:

- Declaration of an emergency evacuation;
- Location of refuge chambers;
- Spatial characteristics of the virtual mining environment, including the depiction of visual cues that can aid navigation;
- Inclination of the terrain, the speed at which it can be traversed, and the respective levels of physical effort required to do so;
- Environmental conditions that can affect the ability to reach a refuge chamber;
- Function and capabilities of the self rescuer, cap lamp, and personal radio;
- Lighting conditions of the virtual mining environment;

4.3 The 3D Simulation Environment
An authentic simulation demands that issues relating to physical and functional fidelity are addressed in order to facilitate transfer between the simulation environment and the real world system that is being modelled. To this end, the virtual mining environment will utilise the high visual fidelity inherent in 3D simulation environments that are based on FPS gaming technology to create a perceptible and operable representation of the Challenger mining environment. Aspects of the emergency evacuation procedure at Challenger that are required to be represented with high visual fidelity have been identified with reference to the learning objectives for the problem-solving exercise within the simulation environment:

- 3D model of mining vehicles;
- 3D model of refuge chamber and escape rise;
- Visual cues that aid navigation;
- 3D representation to scale with respect to the dimensions, perspective, and relative distances between objects of the Challenger mining environment;
- 3D model animation of the self rescuer being activated from a first person perspective;
- High fidelity lighting and shadows, and;
- Realistic fire and smoke effects;

Functionally, a number of system wide variables will be used to model the behaviour of the emergency evacuation scenario at Challenger in order to develop feedback within the system. The user will be able to interact with the virtual mining environment in a manner that is consistent with the real world Challenger mining environment providing the information necessary to promote feedback and assess performance.
The spatial characteristics of the virtual mining environment itself will be modelled on those of the real world Challenger mining environment, with a specific focus on the spatial characteristics that are crucial to the satisfaction of learning objectives. In this manner, the dimensions, perspective, and relative distances between objects can be replicated so that the user will be able to construct cognitive spatial representations of the virtual mining environment that are applicable to the real world counterpart during an emergency evacuation scenario.

The control scheme and immediacy with which the system responds to input will support free interaction with the virtual mining environment. In this manner, the illusion of movement will be sustained within the simulation environment whilst also fostering the user's sense of presence and perceived ownership over the learning process.

4.4 Problem-based Learning Components

The degree of learner control afforded to users within the simulation environment will be such that they will be granted control over the extent of their interaction within the virtual mining environment, whilst also receiving support from a facilitator type construct to structure and guide the learning process. This construct will be triggered in response to user and environmental events whereby questions will be posed to the user via audio cues in order to encourage higher order thinking and the justification of actions within the virtual mining environment.

The implementation of a partially learner and facilitator-directed problem-based learning environment will also require a shared level of responsibility for instruction. Explicit learning resources provided at the onset of each problem-solving instance will combine with users assuming responsibility for identifying and utilising the information that is presented within the virtual mining environment to generate effective strategies to achieve the learning goals.

The facilitator construct will be used to inform the user of certain events within the virtual mining environment and also pose questions to the user to assist their search for a solution to a problem. This provides an augmentation to the authentic and immediate feedback of the virtual mining environment itself.

As with the provision of learning resources, the degree of control the learner has over the problem-based learning process is also a factor in determining the orientation of assessment within the simulation environment. Given the implementation of a partially learner and facilitator-directed problem-based learning environment, a combination of process, outcome, and context-based assessment measures will thus be used to gauge the learning outcomes.

Ultimately, the use of question prompts, the immediacy of the simulation environment itself, and a high level of control and user-centric activity will encourage users to relate their new knowledge to their understanding, and understand the manner in which it can be abstracted and reapplied in future problem-solving situations.

5 CONCLUSION

A 3D simulation environment based on FPS gaming technology will be utilised in order to present an authentic and high fidelity representation of the emergency evacuation procedure at Challenger according to a problem-based learning pedagogy. The design of this simulation environment has been based on information provided via a corresponding situation analysis with reference to a design framework that has been derived from the relevant literature. The purpose of this simulation environment is to develop knowledge and experience within users that can be used effectively during a real world emergency evacuation within the Challenger mining environment.

A working prototype of the simulation environment will be available for demonstration at the time of publication.

6 REFERENCES


