An interactive game-based engineering laboratory

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ABSTRACT: Environments enabled by advanced cyberinfrastructure tools are increasingly being used by scientists, engineers and educators for their research, education and training, career development as well as life-long learning. Recently, virtual environments for instructional purposes have begun to be developed using multi-player computer game engines. Most of these projects are still in the early stages of development and are focusing mainly on exploring the suitability of interactive games for remote user interaction, content distribution and collaborative activities. A few other developments are aimed at utilising computer game technology as a platform for the implementation of simulations for personnel training and educational laboratories. After briefly reviewing some educational applications of computer games, this paper discusses an interactive engineering laboratory that was designed, implemented and piloted at Stevens Institute of Technology. An overview of the system architecture, capabilities and functions is given. Finally, a pilot implementation into a junior-level engineering course is described and the results of this study are summarised.

INTRODUCTION

Students have been found to favour learning experiences that are digital, connected, experiential, immediate and social [1]. They typically prefer learning-by-doing (activity) over learning-by-listening, and often they study in groups [2]. Computer games, the Internet, e-mail, cell phones, instant and text messaging and social networking have become integral parts of their lives, facilitated by that fact that these tools have become ubiquitous and affordable. Most of today’s pupils are accustomed to, and skilful in, playing computer games. The appeal of computer games lies in features such as active participation, intrinsic and prompt feedback, challenging but achievable goals, and a certain degree of uncertainty and open-endedness. Researchers are beginning to view gaming technology as having applications in fields with other benefits besides being applied for entertainment purposes [3]. Recent research indicates that game-based educational environments can lead to high learning results in areas where interdisciplinary knowledge is necessary and where skills such as problem solving, critical thinking, group communication, debate and decision making are important [4]. Computer games share many characteristics with problem-solving activities, such as the construction of a problem context, multiple paths to a specific goal, collaboration between multiple players, unknown outcomes, and elements of competition and chance. Therefore, they are considered to be powerful learning tools that provide high learner motivation and increase the likelihood of the desired learning outcomes being achieved.

Today’s computer games are developed using so-called game engines, which represent the essential core of these games providing reusable functionality (e.g. graphics rendering, audio output, in-game physics modelling, game logics, rudimentary artificial intelligence, user interactions, as well as multi-user networking). They are usually accompanied by a software development kit (SDK), which enables the development of customised content to be utilised by others in conjunction with the original game engine. Several computer game engines are commercially available and have been used to implement very realistic massive multiplayer game environments (e.g. World of Warcraft [5], Everquest II [6], Second Life [7]). Currently, some of the better-known commercial game engines are Epic Game’s *Unreal* engine [8], id Software’s *DOOM 3* engine [9] and Valve Corporation’s *Source* engine [10]. The games developed using these game engines are predominantly *first person shooter games* in which the game users control the movements and actions of virtual characters, known as avatars, and the visual display mimics the perspective of what the in-game characters would see with their own eyes. Taking advantage of this technology for offering truly immersive and interactive learning experiences has now become a real possibility.

EDUCATIONAL APPLICATIONS OF GAME ENGINES

The existing computer game engines can be utilised as a means for creating educational tools [11]. It should be noted, though, that creating educational games does not only consist of adding educational content to some existing game environment, but rather the software itself has to be designed based on evidence that the particular educational content is effective in a specific computer game environment [12]. Such game-based educational environments involve synchronous student interaction through a computer network, and they benefit the students by stimulating the different modalities of learning, i.e. visual, audio, read/write and kinaesthetic [13]. For example, the Immersive Education Initiative [14] is an international collaboration of universities, colleges, research institutes and companies that are working together to define and develop open standards, best practices, platforms, and support communities for virtual reality and game-based learning and training systems. Similarly, a game-based collaborative virtual environment that supports the early stages of design in the context of architectural education was introduced [15].

A set of realistic and sophisticated simulations covering chemistry, physics and planetary motion was developed at Brigham Young University [16]. The Harvard Law School and the Harvard Extension School [17] created a virtual environment in Second Life, and a course called *CyberOne*: *Law in the Court of Public Opinion* [18] became the first class there to be offered in part in a virtual environment. As another example, the Center for Media Design [19] at Ball State University created *Middletown Island* in *Second Life* for a freshman composition course that is taught as a virtual class. In a virtual chemistry laboratory [20], thousands of test tubes holding molecular solutions were photographed and a simulated laboratory environment was created, which enables students to mix chemicals in virtual beakers and observe the resulting chemical reactions. A physics laboratory [21] contains simulations of some fundamental experiments on quantum chemistry, gas properties, mechanics, planetary motion, density, circuits and optics. Based on *Half-Life 2* [22], *Garry's Mod* (i.e. modification) [23] was developed, which represents a *physics sandbox* that allows the players to spawn objects, connect them with various constraints and, thus, create working systems that obey the laws of physics. Similarly, the *Wire Modification* project [24] to *Garry's Mod* allows users to wire gates, sensors, inputs and outputs together in order to form working primitive computers or machine-like contraptions. In conjunction with the *Havok* physics engine [25], this *Mod* can be used to control various mechanical processes.

Various groups have also explored training systems based on computer game engines. For example, simulations of military scenarios [26][27] were developed for training purposes and the potential for using multi-agent tactical simulations as training software using the *Unreal* [8] game engine was investigated [28]. Various computer game platforms [29][30] were used to develop virtual simulations of accident scenarios in chemistry laboratories. Also, a video game for training fire-fighters to efficiently use trucks, equipment and personnel in fighting fires was developed and tested by simulating an emergency situation in downtown Los Angeles [31].

A GAME-BASED ENGINEERING LABORATORY

Overview

A virtual laboratory environment was designed, implemented and piloted at Stevens Institute of Technology (SIT) [13]. In this collaborative laboratory environment (Figure 1), the educational content is tailored to address the students' different learning modalities. A number of predefined laboratory scenarios can be scripted [12]. In these scenarios, the students can collaborate in performing the various tasks involved in the laboratory assignments. In addition, the experimental scripts embedded in the system allow the instructor to monitor whether or not all students comprising a laboratory group are actively participating and collaborating in the assigned laboratory tasks. These are widely considered two crucial factors in improving learning.

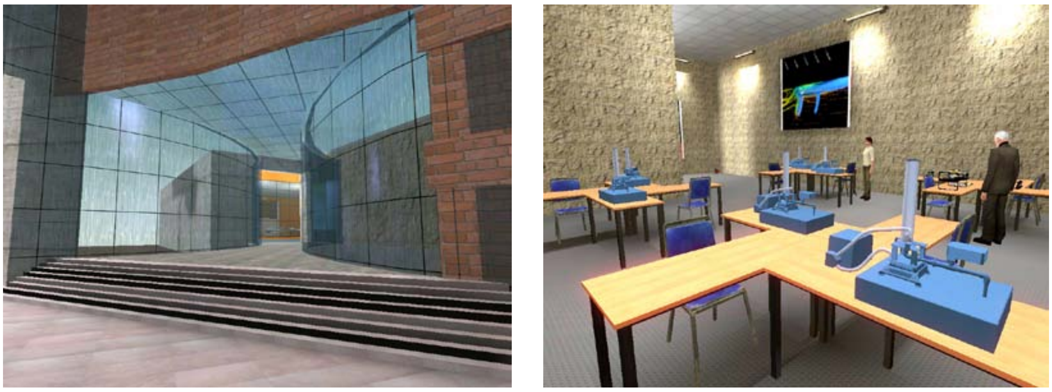

Figure 1: Virtual laboratory environment.

The virtual laboratory environment at the SIT consists of the following three main components (Figure 2):

- a game-based virtual laboratory facility, where the students obtain laboratory instructions, divide the tasks among themselves and assemble a virtual experimental setup;
- a remote laboratory module that the students connect to from inside the virtual laboratory facility to perform real-time experimental procedures based on actual physical hardware via the Internet, and
- a virtual laboratory module that the students use to simulate experimental procedures that go beyond those possible with the physical hardware.

Figure 2: Collaborative laboratory environment [13].

Laboratory Scenarios

Each laboratory session follows a scripted scenario (Figure 3). At the beginning of a laboratory session, the students are given a tutorial describing the experiment scenario and introducing them to the capabilities and functions of the game-based laboratory environment. Specifically, this tutorial informs them on how to log into the experiment Web page, how to customise their game avatars (i.e. gender, outfit, physical appearances, etc.), how to divide the tasks between the group members, how to use the various built-in features of the laboratory system, how to get feedback from the instructor and, finally, how to carry out the actual experimental procedures using either a remote laboratory module and/or a simulation module.

Figure 3: Scripted laboratory scenario.

After introducing the students to the general concept of the game-based learning environment as well as to the specific experimental setup, a knowledge test can then be administered to the students to assess their preparedness for the specific laboratory procedure and possibly guide them to additional instructions, if needed. Subsequently, the students carry out the laboratory assignment, starting with the assembly of the experimental apparatus within the virtual laboratory environment (Figure 4). Subsequently, they either carry out experimental procedures using a remotely accessible actual experimental setup [32] or perform virtual experiments using a software implementation of the experimental setup (Figure 5). Finally, the laboratory session can be concluded by a second knowledge test to evaluate the learning effectiveness of the laboratory session.

Figure 4: Experiment components of an industrial plant emulator and partially assembled setup.

Figure 5: Integrated access to remote and virtual experiments.

Sample Implementation

A sample implementation of the virtual laboratory environment using the *Source* game engine [10] was completed at the SIT. The laboratory exercise involves an industrial plant emulator designed for experiments with different rotating bodies connected by a gear-belt mechanism. This system is designed to introduce the students to the modelling of inertia, friction, backlash and stiffness phenomena in machines. The experimental setup consists of a drive disk and a load disk, which are connected via a speed reduction unit (Figure 6). Furthermore, the emulator system is equipped with a friction brake and encoders connected to a drive motor and a disturbance motor. The experimental setup allows students to vary the inertia of the device by placing weights at various locations on the drive and load disks as well as to change the gear ratio in the speed reduction unit and to install belts with different stiffnesses. Thus, this system can be used to demonstrate various concepts related to gears, belts, inertia of machine elements, and rigid versus flexible machines [33].

Pilot Study

A pilot study of the virtual laboratory environment was conducted in a junior-level mechanical engineering course at the SIT using the industrial plant emulator system described above. While it took most of the student groups approximately thirty minutes to carry out the corresponding laboratory assignment, some students with additional questions or in need of extra help regarding the tutorial took somewhat longer. Knowledge tests were administered to the students before and after experiencing the virtual laboratory environment, and the comparison of these knowledge test results were used to evaluate the learning effectiveness of the virtual laboratory environment. Upon completion of the laboratory session, the students were also asked to complete a questionnaire, which was then analysed in order to obtain further anecdotal insights into the students' opinions about, and attitudes toward, the game-based laboratory approach.

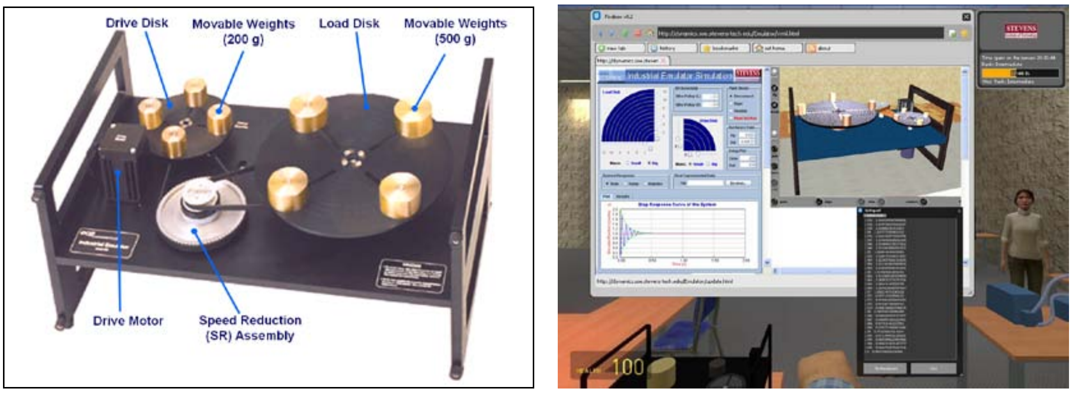

Figure 6: Remotely accessible industrial plant emulator system and corresponding simulation.

The assessment data obtained from the pilot study indicated that the students improved their knowledge of the concepts taught in the lecture component of the class and expressed general satisfaction with this laboratory approach (Figure 7) [34]. The results of the assessment study furthermore suggest that game-based learning environments hold good potential for developing into an educationally viable complement to traditional pedagogical tools and, thus, warrant further development and investigation.

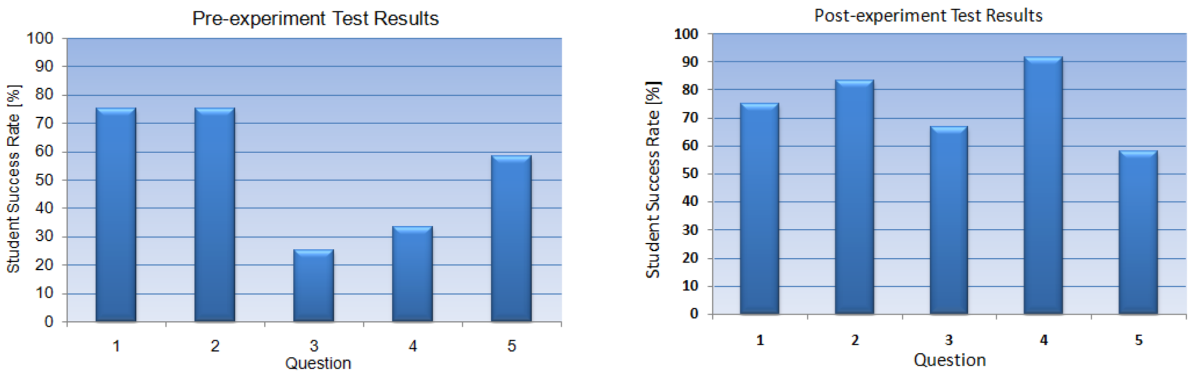

Figure 7: Comparison of test results in pilot study.

CONCLUSIONS

Applications of commercially available computer game engines for implementing virtual environments for education and training purposes were reviewed. Even though most of these systems are still in the early stages of development, they have already given a glimpse of their potential for providing effective learning and training experiences in various fields. An interactive virtual environment for engineering laboratories was designed, implemented and piloted in a junior-level engineering course. The results of the pilot study were encouraging, both based on the learning outcome assessment and the collected student feedback.

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