REVIEW OF THE STATE OF THE ART IN VIRTUAL LEARNING ENVIRONMENTS BASED ON MULTI-PLAYER COMPUTER GAMES

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Abstract

Scientists, engineers and educators are increasingly using environments enabled by advanced cyberinfrastructure tools for their research, formal and informal education and training, career development and life-long learning. For instance, academic institutions as well as private training and education companies have recently started to explore the potential of commercially available multi-player computer game engines for the development of virtual environments for instructional purposes. Most of these developments are still in their early stages and are focused mainly on investigating the suitability of interactive games for remote user interaction, content distribution and collaborative activities. Some of the ongoing projects have additional research objectives, such as the analysis of patterns of human behavior and the study of the collaboration between users and their interaction with virtual environments. A few other developments are aimed at utilizing computer game technologies as a platform for personnel training and educational laboratory simulations. This paper provides a review of the current state of computer game applications, with a special focus on education and training implementations.

Introduction

Today's students have been described as preferring learning experiences that are digital, connected, experiential, immediate, and social.[1] They appear to prefer learning by doing rather than learning by listening and often choose to study in groups.[2] With technology getting more ubiquitous and affordable, computer games, the Internet, e-mail, cell phones, instant and text messaging and social networking have become integral parts of their lives. Most high school and college age pupils are highly accustomed to and very skillful in playing computer games. A remarkable feature of video games is their power to motivate. Computer game features such as active participation, intrinsic and prompt feedback, challenging but achievable goals, and a certain degree of uncertainty and open-endedness contribute to these games' appeal. Besides being used for entertainment purposes, gaming technology is starting to be seen by researchers outside the game industry as having applications in fields with more obvious social benefits.[3]

Recent research has found that computer games can achieve 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 of high importance.[4] Games have many characteristics of problem solving activities, for instance the construction of a problem context, multiple paths to a specific goal, collaboration in the case of multiple players, unknown outcomes, etc. Furthermore, they add elements of competition and chance. Players construct identities, merge the possibilities of action in the game environment with their own desires as players and hypothesize about the identity of the character they are controlling on a screen. From these perspectives, games are seen to offer increasing levels of challenge, the gradual revelation by the learner of systems and rules governing individual interactions, and the experience of exploring and developing different identities and the tools and practices that support these. It is for these reasons that games are often held up as examples of powerful learning environments. Games can provide the motivation to learn, thus increasing the likelihood that the desired learning outcomes will be achieved. To expand the scope of the computer games from playing to learning and teaching[5], some of the most important game elements that should be incorporated into a virtual learning environment are:

- Use of first person game perspective so that each student feels as close as possible to the real experience of a traditional course
- Customization of the avatars' appearance so that they look like casually attired, which enhances the students' feel of immersion
- Tasks that challenge the students and drive collaboration
- Switching between simplified and detailed interfaces while providing an appealing access to in-depth information on relevant concepts
- Certain exaggerations in responses of interaction between game objects, such as damage after collisions
- A pause function that allows the students to take a time-out (e.g. to find complementary information)
- A speed-up/slow-down function to provide the students with a means to perform the tasks at their desired pace
- A replay option to have a chance to repeat a task
- Accessible communities for sense of belonging through virtual laboratory multi-user servers with interaction among the students
- Choosing between multiple skill levels to better align difficulty with capability (i.e. raising the challenge as the students' capabilities increase)

Today's games developed using game engines can be played on personal computers, on game consoles, and on cell phones, and they can be created without the use of programming languages (using editing tools and software development toolkits). A game engine is the essential core of a computer game with reusable functional components (e.g. graphics rendering, audio output, in-game physics modeling, game logics, rudimentary artificial intelligence, user interactions as well as multi-user networking) and is usually accompanied by a software development kit (SDK). These SDKs enable others to develop customized content that is then utilized in conjunction with the game engine. Currently, several computer game engines are commercially available and have been used by developers to create very realistic massive multiplayer game environments (e.g. World of Warcraft[6], Everquest II[7], and Second Life[8]). At present, some of the better known commercial game engines representing the cutting edge of technology in first person perspective graphics are Epic Game's Unreal engine[9], id Software's DOOM 3 engine[10] and Valve Corporation's Source engine.[11] The type of games that these engines were designed for are predominantly "first person shooters", where the user controls the movements and actions of a computer character and the visual display mimics the perspective of what the in-game character would see with his/her own eyes. Taking advantage of these diverse delivery mechanisms to offer truly immersive learning experiences has become a real possibility now.

Recently, computer games also started to be used in a wide variety of areas, such as education, project management, weather forecasting, military training, healthcare, archeology, simulators, and others. However, creating educational games is not simply a matter of adding educational content to some existing game environment. Instead, the software itself should be designed based on evidence that the particular educational content can be effectively delivered in a computer game environment[12].

Classification of Game Engine Applications

Applications of computer game can be classified into those for educational, training, research and other purposes.

Educational applications: Taking advantage of the favorable characteristics of computer games, existing multi-player computer game engines can be utilized as a means for creating educational tools that have the potential for enabling students to learn in an engaging manner. These game-based educational simulations involve synchronous student interaction through a computer network, and they will benefit the students by stimulating the different modalities of learning, i.e. visual, audio, read/write and kinesthetic[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 communities of support for virtual reality and game-based learning and training systems. It is designed to immerse and engage students in the same way that today's best video games grab and keep the attention of players. Similarly, a game-based collaborative virtual environment that supports the early stages of design in the context of architectural education was introduced.[15]

Training: Various groups have also explored training systems based on computer game engines, stimulated by the affordability of such systems in combination with the ubiquity of powerful personal computers. For example, simulations of military scenarios[16,17] were developed for training purposes. Similarly, the potential for using multi-agent tactical simulations as training software was investigated[18], wherein the Unreal[19] game engine and its associated main simulation servers were interfaced, thus enabling the use of common PCs as a low cost replacement for the expensive proprietary equipment used previously in such tactical simulations. Various computer game platforms[20,21] were used to develop virtual simulations of accident scenarios in chemistry laboratories, stipulating that this approach is more effective than distributing safety regulations to the students in the traditional paper form. For example, a video game was developed by students at DHS' CREATE Center to train fire fighters to efficiently use trucks, equipment and personnel in fighting a fire (see Figure 1). It simulates an emergency in downtown Los Angeles and is being tested out by the city fire department.[22]

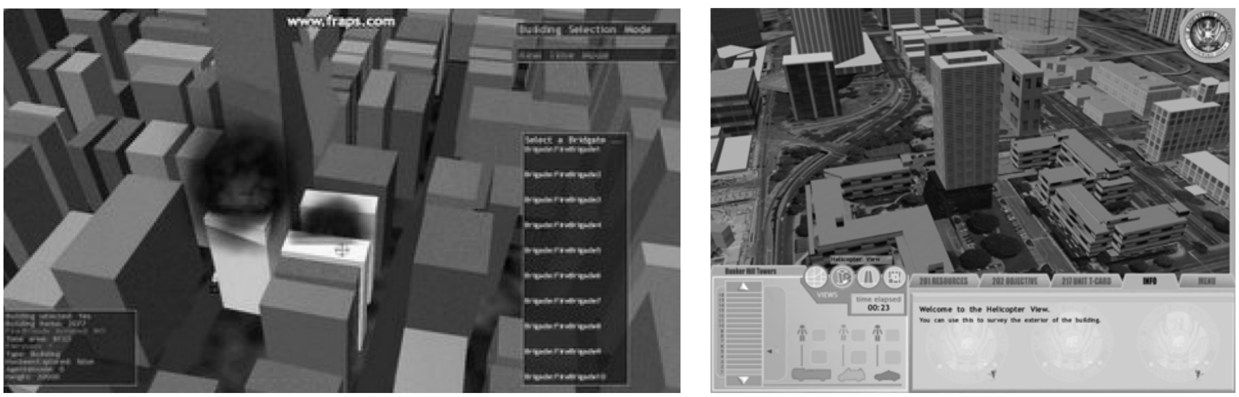

Figure 1: Screenshots from DEFACTO[22] "Firescope Simulation: Incident Commander"

Research and other: The Unreal game engine formed the basis for research aiming to achieve refinements of the human controller and robotic interface of urban search and rescue robots.[23] Several computer game engines were investigated as flexible, robust and inexpensive environments for exploring the development of human level artificial intelligence in complex environments.[24] Software systems that are capable of adapting their responses to the context of the attempted user task were implemented using a game engine.[25] In the open-source CaveUT project[26], the Unreal game engine was used to enable immersive projection-based virtual reality applications through displays in multi-screen enclosures, which provide users with a high-performance, low-cost virtual reality alternative.

Educational Applications

Recently, massive multiplayer online games such Second Life[27] (created by Linden Research, Inc.[28]) have become more than just virtual environments for chatting. Second Life was programmed to be an open-ended environment and features a high level of flexibility. It enables its users to customize their avatars as fantasy creatures and build almost anything they could imagine. An increasing number of organizations and institutions are using it to implement applications that have a purpose other than providing for an entertaining pastime, and it has developed into a platform used for educational, research and even therapeutic purposes. For instance, it became a place for business school students to test entrepreneurial talents. In a program presented at the 2005 Supernova Conference on Emerging Technologies and Business Implications[29], students of the Wharton School and conference attendees were immersed in Second Life and encouraged to start businesses, to advise some businesses already in existence and to compete against each other. Elon University in North Carolina[30] is another business school that is employing Second Life as a way of building and testing entrepreneurial skills.

Second Life and many other massively multiplayer online (MMO) games offer the ability to start in-world businesses that sell things like custom clothing, vehicles, housing and more for use inside of the game. What sets Second Life apart is the freedom to create and have open-ended social interactions with all its members who pay a one-time fee. Second Life’s almost 17 million currently registered users[31] surpass other MMOs, such as World of Warcraft, EverQuest and Ultima Online, just to name a few.[32] The success of Second Life is probably based on the fact that many industry observers feel that it offers the best platform for mixing social interaction, play and the opportunity to tackle serious issues, since the game is not restricted to any one narrowly defined objective.[33]

The Berkman Center for Internet & Society at Harvard Law School and the Harvard Extension School[34] is a virtual environment created in Second Life on an in-world island. A course called “CyberOne[35]: Law in the Court of Public Opinion” is the first class at Harvard University and the Harvard Extension School to be offered in part in a virtual environment. The corresponding course video, lecture and project materials are available for free in Second Life to anyone with an Internet connection. Students taking the course meet weekly with their instructors and fellow students in Second Life for usual classroom activities as well as innovative projects that take advantage of the large number of possibilities of the Second Life environment. CyberOne represents an ongoing process of pedagogical innovation and experimentation, with inquiry into openness, new technologies and related policy, learning and social media. Furthermore, a wide spectrum of Web issues, including governance, privacy, intellectual property, antitrust, content control and electronic commerce is also explored.

As another example, Middletown Island was created in Second Life by the Center for Media Design[36] at Ball State University in Muncie, Indiana, for the freshman composition course, which was taught as a virtual class. The focus of this class was to help students to learn how to research and write in a virtual setting. In the Second Life implementation of the course, the students sat in a circle, debated and communicated via a public instant messaging system. Then, the instructor printed the recorded dialogue as classroom notes. As a semester project, the students built an exhibition area and invited other Second Life users to visit and review their work. Reportedly, in excess of 300 people from around the world visited during a two-hour period and gave the students’ work an exposure far greater than would have ever been possible using conventional methods.

Y Science Laboratories developed at Brigham Young University[37] is a set of realistic and sophisticated simulations covering chemistry, physics, and planetary motion. In these laboratories, students are put into a virtual environment where they are free to make the choices and decisions that they would confront in an actual laboratory setting and experience the resulting consequences.

In a virtual chemistry laboratory[38] (see Figure 2), thousands of test tubes holding molecular solutions were photographed. Then, working with video game designers, a simulated laboratory environment that enables students to mix chemicals in virtual beakers and observe the resulting chemical reactions was created. Since its conception, the virtual chemistry laboratory has had students at computer terminals around the country perform experiments that would be too costly or dangerous to perform at their local high schools.

The physics laboratory[39] (see Figure 3), contains seven different laboratories that include simulations of the fundamental experiments in quantum chemistry, gas properties, calorimetry,

Realistic outcomes are shown when the wrong metals are dropped into the calorimeter
Figure 2: Virtual Chemistry Laboratory[38].

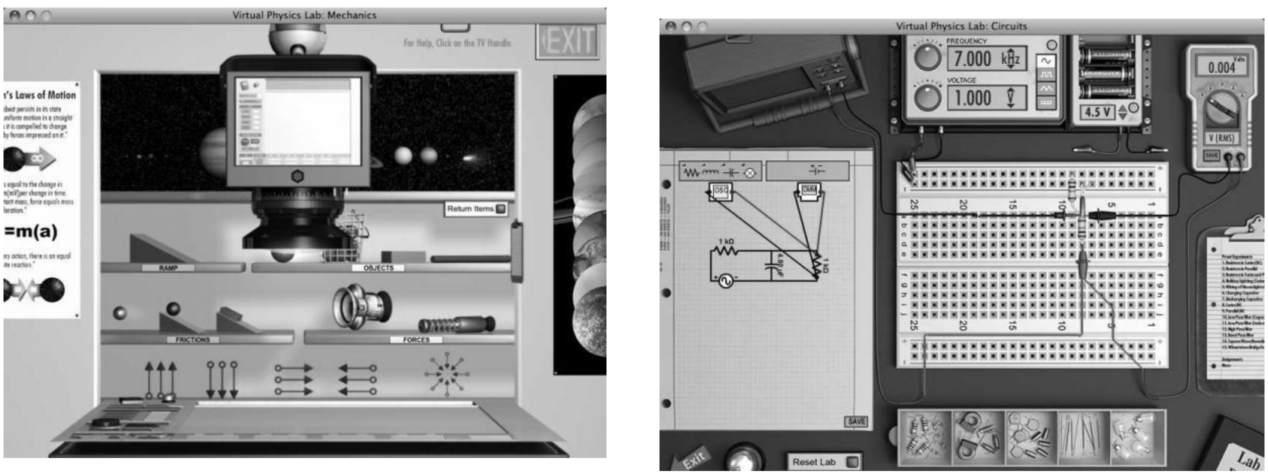

Figure 3: Virtual Physics Laboratory[39].

mechanics and planetary motion, density, circuits, and optics. For example, the mechanics laboratory provides students the flexibility to perform many fundamental experiments on the basic concepts of Newton's laws and planetary motion that are easier to model in a simulated situation rather than in a real laboratory. The ability to control the friction, forces, and physical parameters of motion enables students to easily use equipment that can be found in most instructional laboratories and some equipment that would be less readily available. Students are able to measure speeds and distances, describe the motion of objects using graphs, interpret data, understand our solar system, and gain a foundation for various concepts in physics. These experimental results can then be used to validate Newton's laws, demonstrate the interplay between force and motion, demonstrate the concept of conservation of momentum, and study the intricacies of the solar system under variable initial conditions and parameters.

"Cell Biology", a project where students collect data from the cells of an onion root and use it to calculate the duration of each phase in the cells' division, was developed at the University of Arizona[40]. The science courses offered by some online high schools draw on multiple Internet sites that provide data and subsequently lead students through analyses.

At the RWTH Aachen in Germany, research on spaces and tools in real and virtual educational environments (WISE environments[41]) is being pursued.[42] This work is designed as the starting point of a thread of inquiries into linking real-world and virtual learning environments and exploring the resulting synergies.

SecondReiff[43], a virtual extension of the campus of RWTH Aachen, offers the environments and tools through which students and faculty can communicate and work together productively in new ways. The project features three distinct, vertically stacked zones. A so-called “XXL Workbench” located at sea level enables the students to practice architectural design collaboratively in real time, upload necessary architectural drawings onto the grid and manipulate the topography (see Figure 4). Above this zone, reference images can be posted in a Media Center. Lastly, a General Communications Area forms the top level, which is built upon the very same logic that is used in Second Life itself. This area is divided into a mainland with project-specific areas and many islands claimed by individual students. Besides the immediately visible differences to most other projects in Second Life, SecondReiff is based on another concept. While most Second Life locations limit their interactions to avatar-to-object relationships, SecondReiff offers tools and scripts that actually link avatars to one another and expand the available modes of communication and information exchange between them. Communication between the avatars, formal presentations and the ability to actually collaborate in real time and on a large scale represent an environment with previously unimaginable productivity and technological possibilities.

Based on Half-Life 2[45], a first-person shooter computer game using the Source game engine, Garry's Mod (i.e. modification[46]) 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, such as a controllable model of a car (see Figure 5), Similarly, the Wire Modification project[47] to Garry’s Mod allows players to wire gates, sensors, inputs and outputs together in order to form working primitive computers or machine-like contraptions. The wires used to connect the electronic elements are energy beam models that act as a medium to carry the output of one wired entity to the input of another. The remaining electronic elements are programmed to simulate the logic of their real-life counterparts. In conjunction with the Havok physics engine[48], this can be used to control various mechanical processes with wire-enabled constraints, special game functions or entities that affect object parameters.

Garry’s Mod and Wire Modification inspired the development of a virtual laboratory environment at Stevens Institute of Technology (SIT). In this immersive collaborative virtual laboratory environment (see Figure 6), the educational content is tailored to address the students’ different learning modalities. A number of predefined scenarios, that exercise the students’ problem solving skills by mimicking typical problems that might occur when carrying out actual hands-on experiments can be scripted. In addition, the experimental scripts imbedded within the system allow one to monitor active participation and collaboration by all students of a laboratory group, which are considered two crucial factors in improving learning. The students can work collaboratively in teams to perform the various tasks involved in the experiment. The virtual laboratory environment consists of the following three main components:

- a game-based virtual laboratory facility where the students obtain laboratory instructions, divide the tasks amongst 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.

Before conducting the three stages of game-based experiments, the students are handed out an experiment scenario as a tutorial to introduce them to the capabilities of the game-based environment and to inform them on how to log into the experiment Web page, how to customize their

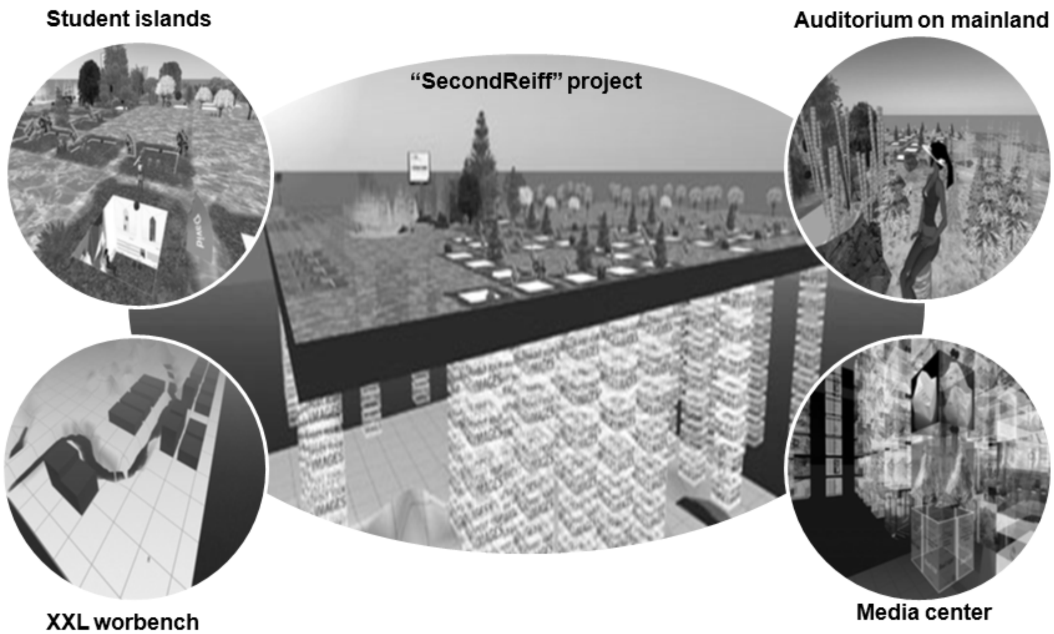

Figure 4: "SecondReiff" architecture project[44].

Figure 5: Controllable model of a car created using Garry's Mod and Wire Modification[49].

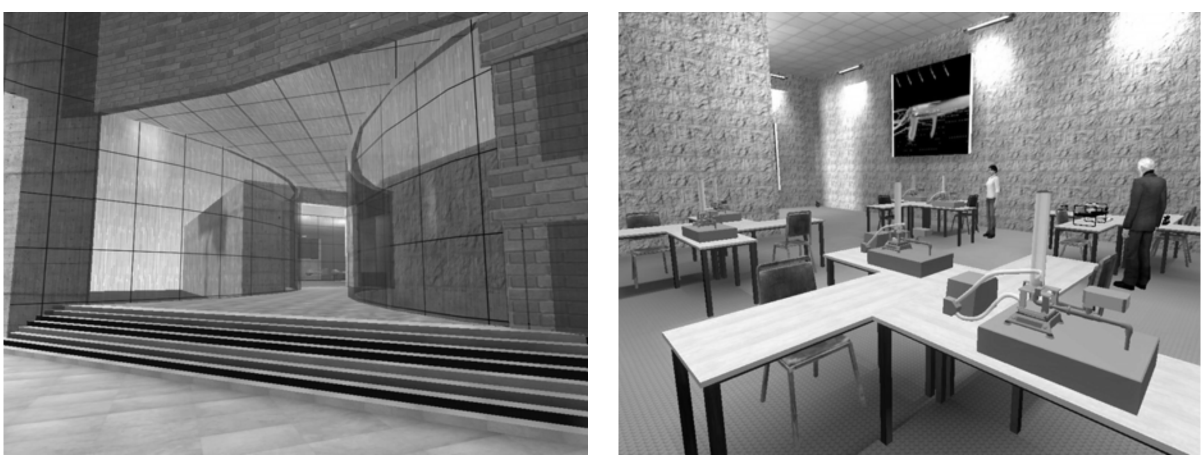

Figure 6: Virtual laboratory environment at Stevens Institute of Technology.

game avatars (i.e. gender, outfit, physical appearances, etc.), how to distribute the work load amongst the team members, how to select and use the built-in features of the game-based system, how to get feedback from the instructor and finally how to connect to the remote experiment module. During a pilot implementation in a junior-level mechanical engineering course at SIT, most of the laboratory sessions of the student groups lasted approximately half an hour, but some students who had additional questions and needed extra help with the tutorial stayed longer for further assistance. After introducing them to the general concept of the game-based learning environment and to the specific experimental setup, the system enables the students to assemble an experimental apparatus (an industrial emulator system used to demonstrate the concepts of gears, belts, inertia of machine elements, rigid vs. flexible machines) within the game-based virtual laboratory environment[50] (see Figure 7) and subsequently to either carry out experimental procedures using a remotely accessible actual experimental setup of the industrial emulator system or perform virtual experiments using a software implementation of the experimental setup.[51] In addition, knowledge tests were given to the students before and after experiencing the virtual learning environment, respectively. The comparison and analysis of these knowledge test results were used to evaluate the learning effectiveness of the developed virtual laboratory environment. A questionnaire was administered to the students and then analyzed in order to obtain further anecdotal insights into the students' opinions about and attitudes toward the game-based laboratory approach.

Using the approach of combining the game-based laboratory environment with remote and virtual experiments, the students can repeat the laboratory experiments more than once at their own pace as opposed to having to complete the laboratory procedure during the allotted time as in the traditional hands-on mode. The assessment data obtained from the pilot at SIT 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.[52] The results of the assessment study furthermore suggest that game-based learning environments have the potential for developing into an educationally viable complement to traditional pedagogical tools and warrant further investigation (see Figure 8).

Training Applications

An elaborate surgery simulator is currently being developed at Rensselaer Polytechnic Institute. This simulator will allow surgeons to manipulate virtual human organs in real time, thus enabling them to acquire crucial skills without using cadavers or risking human lives (see Figure 9). The ultimate goal of this project is to create a complete virtual human. Upon completion of the required giant database of virtual human anatomy models, the simulation would look and feel real and allow the user to "touch" and manipulate it using haptic interfaces such as SensAble Technologies' Phantom devices[53] or Meta Motion's CyberGlove.[54]

Another human simulation[56] currently under development is HumanSimTM. This system is being created based on the Unreal game engine by integrating it with a high-fidelity physiologic-pharmacologic model for experiential learning. The simulation scenarios are being programmed so as to emphasize learning by doing and to provide training to proficiency in rare, complicated or otherwise error-prone tasks. Also, two instructional 3D simulations for heart surgery procedures were developed, which demonstrated new treatments for a trial fibrillation in the heart. The first animation was an open chest procedure while the second demonstrated laparoscopic access in a closed chest setting (see Figure 10).

So far, the few surgical simulators currently on the market are not very popular yet with the medical community, largely because of their lack of realism and since they rely mostly on simplistic graphics for representing human tissues. Furthermore, the haptics technology used to let surgeons "feel" their actions is not mature enough yet for simulating interactions with soft biological tissues.

Figure 7: Sample laboratory scenario.

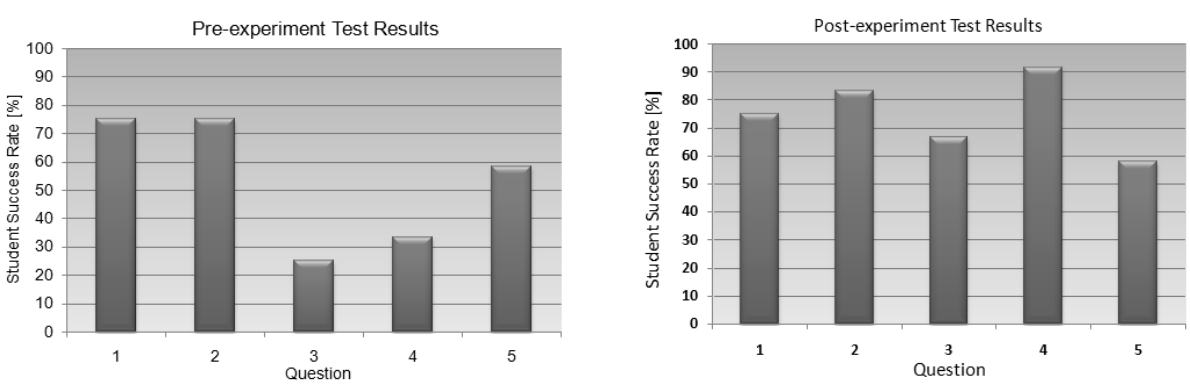

Figure 8: Comparison of test results to evaluate learning effectiveness of game-based laboratory.

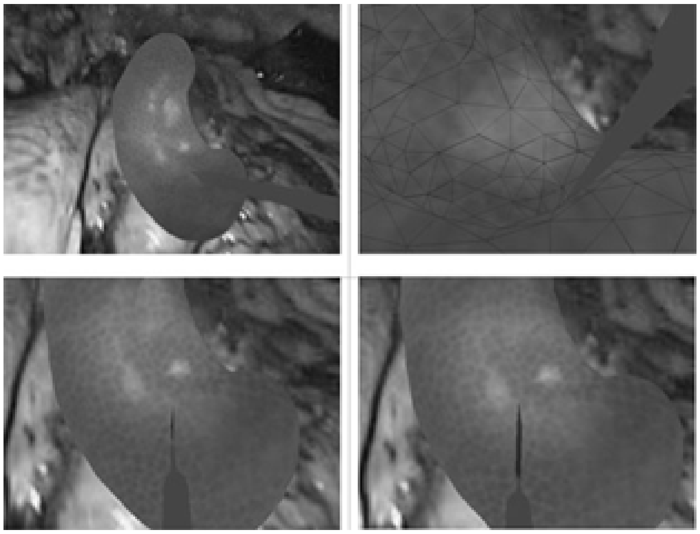

Figure 9: Virtual model of surgically cutting a kidney[55].

A virtual training space in Second Life named Play2Train was designed as part of Idaho's Bioterrorism Awareness and Preparedness Program.[57] This virtual environment spreads over two Second Life islands, whereby one island hosts a virtual town and the other a virtual hospital. It represents a virtual world designed specifically to meet the distinctive training needs of the professionals who will be on the scene in the event of any large-scale disaster (see Figure 11). Play2Train provides opportunities for training through interactive role playing and is the foundation of what would be the emergency preparedness educational virtual environment. With this development, training healthcare professionals and emergency responders for sudden large-scale catastrophes such as natural disasters, bioterrorism attacks and outbreaks of infectious diseases has taken on a new life.

Other Applications

Computer games have also found a number of therapeutic and social applications. For example, a simulation designed to employ computer game technology for lessening war trauma is available to a small number of patients at several sites, including the Veterans Administration Medical Center in Manhattan, the Naval Medical Center in San Diego, Emory University School of Medicine in Atlanta and Walter Reed Army Medical Center in Washington. This simulation was created to treat Iraq war veterans who are suffering from post-traumatic stress disorder. It uses a variety of images and sounds, such as a Blackhawk helicopter circling overhead, insurgents hiding on a roof and launching a rocket-propelled grenade, the animation of a violently shaking ground, and plumes of black smoke that cloud the vision (see Figure 12). In this type of exposure therapy, the patients are asked to confront their memories of a trauma by imagining and recounting it in detail. The immersive features and enhancements of virtual reality systems make this exposure therapy more effective than other treatments.[58]

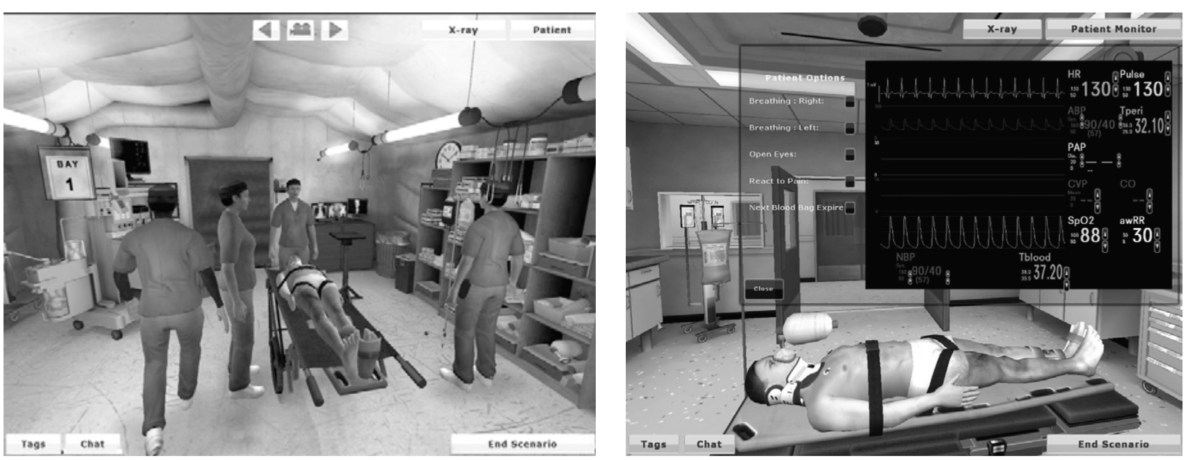

Figure 10: Healthcare[56] training Simulation HumanSimTM.

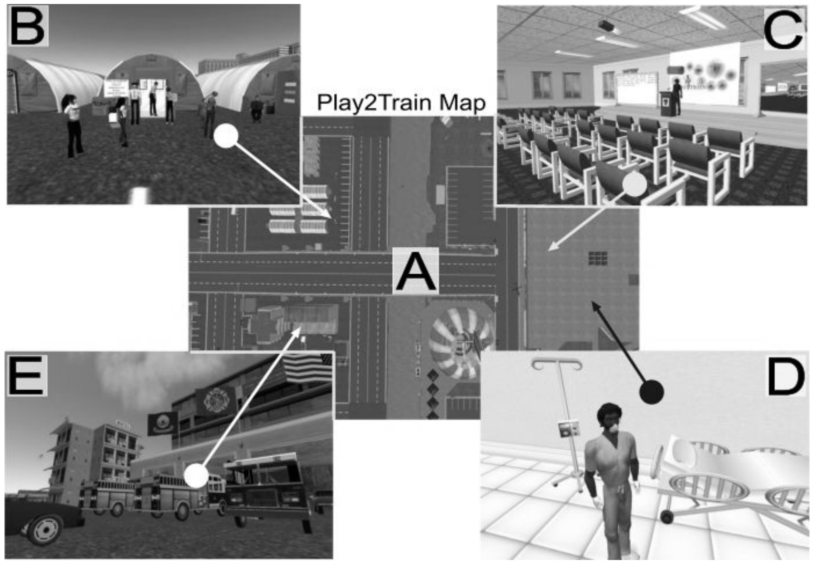

Figure 11: Play2Train virtual training space environment[57].

Figure 12: Virtual environment and projected simulation images[59].

Second Life has also been used by psychologists to help abused children rediscover social skills. Similarly, a project called Live2give[60] was undertaken by nine adults with cerebral palsy. The nine group members share a single Second Life avatar. The objective of this project is to provide its members with a forum in which they can share in the everyday personal interactions that most people take for granted and get to experience being around other people without being judged. Another project that has its own in-world island in Second Life is Brigadoon[61], an innovative online community for people dealing with Asperger's Syndrome and Autism. In the same way as Live2give, this project's goal is to try out the social interactions that for people with these medical conditions are so hard to experience in the real world.

Conclusions

Several applications of commercially available computer game engines for implementing virtual education and training environments were reviewed. While these systems are still in the early stages of their development, they have already provided us with glimpses into their tremendous potential for creating effective learning and training experiences in various fields, including education and student laboratories, medicine as well as disaster response and military training.

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Bibliography

1. An EDUCAUSE e-Book, (2008), “Learning spaces”: http://www.educause.edu/LearningSpaces/10569.

2. Kolb, D. A., (1984), “Experimental learning: experience as the source of learning”, Prentice-Hall, Englewood Cliffs, New Jersey, USA.

3. Freitas, S., (2006), “Learning in immersive worlds: a review of game-based learning”, Prepared for the JISC e-Learning Program: http://www.jisc.ac.uk/media/documents/programmes/elearninginnovation/gamingreport_v3.pdf.

4. Pivec, M. & Kearney, P., (2007), “Games for learning and learning from games”, An International Journal of Computing and Informatics Journal, vol. 31, no. 4, pp. 419-423.

5. Arango, F., (2007), “Tools and concepts to transform a multi-player computer game into a virtual laboratory environment”, Master’s Thesis, Stevens Institute of Technology.

6. World of Warcraft by Blizzard Entertainment; http://www.worldofwarcraft.com/index.xml.

7. Everquest II by SONY Entertainment; http://everquest2.station.sony.com/.

8. Second Life by Linden Research, Inc.; http://secondlife.com/.

9. “Unreal” game engine by Epic Games, Inc.: http://www.unrealtechnology.com/.

10. “DOOM 3” game engine by id Software: http://www.idsoftware.com/.

11. “Source” game engine by Valve Corporation: http://www.valvesoftware.com/.

12. Arango, F., Chang, C., Esche, S. K. & Chassapis, C., (2007), “A scenario for collaborative learning in virtual engineering laboratories”, Proceedings of the 37th ASEE/IEEE Frontiers in Education Conference.

13. Chang, C., Kodman, D., Chassapis, C. & Esche, S. K., (2007), “Immersive collaborative laboratory simulations using a game engine”, Computers in Education Journal, vol. 17, no. 3, pp. 85-92.

14. The Immersive Education, at: http://www.immersiveeducation.org/.

15. Moloney, J. & Harvey, L., (2004), “Visualization and ‘auralization’ of architectural design in a game engine based collaborative virtual environment”, Proceedings of the Eighth International Conference on Information Visualization, pp. 827-832.

16. Fong, G., (2004), “Adapting COTS games for military simulation”, Proceedings of the 2004 ACM SIGGRAPH International Conference on Virtual Reality Continuum and its Applications in Industry, pp. 269-272.

17. Macedonia, M., (2002), “Games soldiers play”, IEEE Spectrum, vol. 39, no. 3, pp. 32-37.

18. Manojlovich, J., Prasithsangaree, P., Hughes, S., Chen, J. & Lewis, M., (2003), “UTSAF: A multi-agent-based framework for supporting military-based distributed interactive simulations in 3-D virtual environments”, Proceedings of the Winter Simulation Conference 2003, vol. 1, pp. 960-968.

19. “Unreal” game engine by Epic Games, Inc.: http://www.unrealtechnology.com/html/technology/ue30.shtml.

20. Bell, J. T. & Fogler, H. S, (2003), “Implementing virtual reality laboratory accidents using the Half-Life game engine, WorldUp, and Java3D”, Proceedings of the 2003 ASEE Annual Conference and Exposition.

21. Bell, J. T., “Virtual reality undergraduate projects laboratory” website: http://www.vrupl.evl.uic.edu/.

22. DHS Student & Alumni Network at: http://www.dhsnetwork.com/documents/Feb07-Gamingandsimulationresearcharticle_000.pdf.

23. Wang, J., Lewis, M. & Gennari, J., (2003), "A game engine based simulation of the NIST urban search and rescue arenas", Proceedings of the 2003 Winter Simulation Conference, pp. 1039-1045.

24. Laird, J. E., (2002), "Research in human-level AI using computer games", Communications of the ACM, vol. 45, no. 1, pp. 32-35.

25. O'Neill, E., Klepal, M., Lewis, D., O'Donnell, T., O'Sullivan, D. & Pesch, D., (2005), "A testbed for evaluating human interaction with ubiquitous computing environments", Proceedings of the First International Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities, pp. 60-69.

26. Jacobson, J & Lewis, M., (2005), "Game engine virtual reality with CaveUT", Computer, vol. 38, no. 4, pp. 79-82.

27. Jacobson, J & Lewis, M., (2005), "Game engine virtual reality with CaveUT", Computer, vol. 38, no. 4, pp. 79-82.

28. Linden Research, Inc.: http://lindenlab.com/.

29. "2005 Supernova Conference", http://www.supernova2005.com/.

30. Elon University: http://www.elon.edu/home/.

31. "Second Life" economical statistics: http://secondlife.com/whatis/economy_stats.php.

32. Comparison of massively multiplayer online role-playing games, http://en.wikipedia.org/wiki/Comparison_of_MMORPGs#_note-mmorpg.com

33. Castronova, E., (2005), "Synthetic Worlds: The Business and Culture of Online Games", University of Chicago Press, 344 p.

34. The Berkman Center for Internet & Society at Harvard Law School and the Harvard Extension School: http://cyber.law.harvard.edu/home/newsroom/pressreleases/harvard_extention_school_to_offer_first_university_course_through_second_life/.

35. "CyberOne: Law in the court of public opinion", course at Harvard University: http://blogs.law.harvard.edu/cyberone/.

36. Center for Media Design at Ball State University: http://www.bsu.edu/cmd/.

37. Y Science Laboratories at Brigham Young University: http://chemlab.byu.edu/.

38. Woodfield, B. F., Andrus, M. B., Andersen, T., Miller, J., Simmons, B., Stanger, R., Waddoups, G. L., Moore, M. S., Swan, R., Allen, R. & Greg Bodily, G. (2005). "The virtual ChemLab project: a realistic and sophisticated simulation of organic synthesis and organic qualitative analysis, Journal of Chemical Education, vol. 82, no. 11, pp. 1728-1735.

39. Virtual physics laboratory at Brigham Young University: http://chemlab.byu.edu/tour/Physics.

40. "Cell Biology", a project at the University of Arizona:http://www.biology.arizona.edu/cell_bio/activities/cell_cycle/cell_cycle.html.

41. WISE environments, research platform at RWTH Aachen: http://www.manuelglasl.de/index.php?article_id=1.

42. Center for Computing and Communication of RWTH Aachen: http://www.rz.rwth-aachen.de/go/id/owz/lang/en/.

43. "SecondReiff", Implementation within WISE at RWTH Aachen: http://www.Manuelglasl.de/index.php?article_id=1.

44. "XXL Workbench" in "SecondReiff" at RWTH Aachen: http://www.manuelglasl.de/files/02_xxl workbench_web.jpg.

45. Half-Life 2 computer game by Valve Software Corporation: http://orange.half-life2.com/.

46. Garry's Modification of the Half-Life 2 computer game: http://en.wikipedia.org/wiki/Garry's_Mod.

47. "WiredMod" Project by Wired Team: http://www.wiremod.com/.

48. "Havok" physics engine; http://www.havok.com/.
49. Model of a car created using Garry's Mod: http://wiki.garrysmod.com/wiki/?title=Land_Vehicles.

50. Chang, C., Arango, F., Esche, S. K. & Chassapis, C., (2007), "On the assembly of experimental setups in virtual laboratory environments", Proceedings of the ASME International Mechanical Engineering Congress and Exposition IMECE'07.

51. Aziz, E.-S., Chang, C., Arango, F., Esche, S. K. & Chassapis, C. (2007), "Linking computer game engines with remote experiments", Proceedings of the ASME International Mechanical Engineering Congress and Exposition IMECE'07.

52. Arango, F., Altuger, G., Aziz, E.-S., Esche, S. K. & Chassapis, C. (2008), "Piloting a game-based virtual learning environment", Computers in Education Journal, vol. 18, no. 4, pp. 82-91.

53. "Phantom" haptic devices by SensAble Technologies, Inc.: http://sensable.com/products-haptic-devices.htm.

54. CyberGlove by Meta Motion: http://www.metamotion.com/hardware/motion-capture-hardware-gloves-Cybergloves.htm.

55. Sandhana, L. (2006), "Pass the virtual scalpel, nurse", slideshow: http://www.wired.com/medtech/health/multimedia/2006/08/71536.

56. HumanSim™ by Virtual Heroes Inc.: http://www.virtualheroes.com/healthcare.asp.

57. "Play2train" developed by Idaho's Bioterrorism Awareness and Preparedness Program: http://irhbt.typepad.com/play2train/.

58. "Virtual Iraq", photo by H. Masuike for The New York Times: http://www.nytimes.com/2007/08/28/health/28game.html.

59. Screen captures of Virtual Iraq simulation software by the University of Southern California.

60. "Live2give" project: http://braintalk.blogs.com/live2give/.

61. "Brigadoon" project: http://braintalk.blogs.com/brigadoon/.

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