AC 2012-3423: SUSTAINCITY A INTERACTIVE VIRTUAL REALITY GAME PROMOTING ENGINEERING DESIGN IN PRE-ENGINEERING CURRICULUM

Dr. Ying Tang, Rowan University

Ying Tang received the B.S. and M.S. degrees from the Northeastern University, P. R. China, in 1996 and 1998, respectively, and Ph.D. degree from New Jersey Institute of Technology, Newark, N.J., in 2001. She is currently an Associate Professor of electrical and computer engineering at Rowan University. Her research interests include virtual reality, artificial intelligence, and modeling and scheduling of computer-integrated systems. Tang has led or participated in several research and education projects funded by National Science Foundation, U.S. Department of Transportation, U.S. Navy, the Charles A. and Anne Morrow Lindbergh Foundation, the Christian R. and Mary F. Lindback Foundation, and industry firms. Her work has resulted in more than 60 journal and conference papers and book chapters. Tang is very active in adapting and developing pedagogical methods and materials to enhance engineering education. Her most recent educational research includes the collaboration with Tennessee State University and local high schools to infuse cyber-infrastructure learning experience into the pre-engineering and technology-based classrooms, and the collaboration with community colleges to develop interactive games in empowering students with engineering literacy and problem-solving.

Dr. Sachin Shetty, Tennessee State University

Sachin Shetty received the B.E. degree in computer engineering from Mumbai University, India, in 1998, M.S. in computer science from University of Toledo and Ph.D. in modeling and simulation from Old Dominion University in 2007. He is currently an Assistant Professor in the Electrical and Computer Engineering department at Tennessee State University. His area of competency includes theoretical and experimental research in network protocols design, security algorithms, and system implementation of cognitive radio networks, and wireless sensor networks. He has authored and coauthored more than 30 technical refereed and non-refereed papers in various conferences, international journal articles, and book chapters in research and pedagogical techniques

Dr. Kauser Jahan, Rowan University
Dr. S. Keith Hargrove, Tennessee State University

S. Keith Hargrove, serves as Dean of the College of Engineering, Technology & Computer Science. He received his B.S. in mechanical engineering from TSU, M.S. from the Missouri University of Science & Technology in Rolla, Mo., and Ph.D. from the University of Iowa. He has worked for General Electric, Battelle Pacific Northwest Laboratories, NIST, Oak Ridge Laboratories, and General Motors. He is an Associate Member of the Society of Manufacturing Engineers, Institute of Industrial Engineers, ASEE, and the Tennessee Society of Professional Engineers. He is also a member of the Tennessee Academy of Science, and has current research interests in virtual and augmented reality, advanced manufacturing systems, systems engineering and management, and minority engineering education.

Mr. John P. Henry

Interactive and Collaborative Virtual Reality Games for Science and Engineering Design in Pre-Engineering Curriculum

Abstract

This paper presents a working-in-progress project that designs a virtual reality (VR) game system to infuse cyberinfrastructure (CI) learning experiences into the pre-engineering classrooms and to promote science and engineering design in context. Using city infrastructure as the theme and engineers solving real-life problems as the scenes, the games of future sustainable city design engage students, particularly prospective and beginning science and engineering students, in CI-enhanced and -enabled science and engineering discovery. More importantly, the games incorporate the access to visualization, simulation and collaboration tools that cater a great interactive and collaborating learning environment for students to digitally explore science and engineering concepts via virtual analysis, design, and production. This paper focuses on the metacognitive and CI tools being conducted by students in various VR game modules, their contributions to student learning, and how the games and tools together fit seamlessly within the pre-engineering curriculum, particularly the Project-Lead-The-Way programming.

Introduction

A number of recent reports make it clear that the United States is losing ground on key indicators of innovation and progress because of its poor performance in teaching math and science. Pre-college education, in particular, is lagging well behind its mandate to educate all children to higher standards especially in areas that prepare students for science, technology, engineering, and mathematics [1]. Therefore, developing educational practices and settings in our K-12 classroom becomes extremely important; especially the ones that promote 21st century skills and help learners build up their "habit of mind" [2] for scientific reasoning and inquiry.

Computing has made possible profound leaps of innovations and imagination, resulting in fundamentally new ways of science and engineering practice [3]. This paradigm shift has a significant impact on the skills needed for a diverse science and engineering workforce who is capable of designing and deploying cyber-based systems, tools and services. However, our education has not kept pace with this evolution, especially at the K-12 level. In fact, there is a crucial need to bring cyberinfrastructure (CI) learning experiences into classrooms of secondary education.

Environmental sustainability has become increasingly prevalent in teaching, valued as not only a motivator for responsible behavior, but also a wonderful context for students to be engaged in developing 21st century skills for the challenges of sustainable future [4].

Inspired by these general remarks, this paper presents a scaffold approach that develops and implements a virtual reality (VR) game system, called *SustainCity* [15], to infuse cyberinfrastructure (CI) learning experiences into classrooms of secondary education. In particularly, a series of project-based participatory VR games of future sustainable city design is being developed and implemented as a replacement of the traditional laboratory activities of the Project-Lead-The-Way (PLTW) [5] courses. More importantly, the games are designed in alignment with the PLTW curriculum to provide not only an attractive and stimulating environment for CI-enhanced and -enabled science and engineering discovery, but also an integrated learning experience for pre-engineering students to see the interconnection between their courses as a progression of increasing design complexity.

CURRICULAR ALIGNMENT

Research [6] indicated that project-based learning promotes students social, methodological and professional competence. Involving students in a series of virtual-world engineering problem solving games with a focus on their contribution to the design of a system motivates students to see the "big picture" of the multi-step solution process. Following in this line of thought, our design chooses a sustainable city, an exquisite combination of interacting systems (infrastructures) that can be designed and analyzed using multidisciplinary engineering and scientific principles, as a broader context for our VR game system. A series of games is then designed in this context with individual focus on particular fundamental science and engineering concepts that contributes to a specific city infrastructure. Integrating all game modules is the core of designing and maintaining an eco-city. Doing this, each game module is self-contained to be used as a stand-alone laboratory activity to a typical PLTW course, depending on its content focus. For schools that offer the entire comprehensive PLTW curriculum, all games can be used in a coordinated manner, where students eventually integrate all game modules in their senior capstone project, resulting in a sustainable city. As the capstone project builds on previous game experiments performed in lower-level courses, students are in a better position to see the interconnection of their curricular courses and appreciate the integrated content values. Table I presents the detailed curricular alignment.

Table I: Integration of VR games in the PLTW curriculum

Context	Infrastructures (Content)	Game Modules	Courses
SustainCity	Power	Power Ville	Principles of Engineering
		ThemoPower	
	Transportation	Mystery of Traffic Lights	Digital Electronics
		Stability	Civil Engineering and Architecture
	Waste	BioEnergy	Biotechnical Engineering

GAME THEME AND DESIGN

In this section, we exemplify the educational process in five experiments of different complexity, one with detailed illustration to showcase the seamless integration of CI facilitation, metacognitive strategies and scientific content in a fun game setting, and the other four with a brief outline of the setup and pertinent science and engineering principles.

<u>Game 1: Power Ville</u> – Energy is at the heart of everybody's quality of life. How to generate and use energy that satisfies the increasing energy needs and combats climate changes at the same time then becomes an unprecedented challenge for a sustain-city development. The core of the game is to bring such real science and engineering design problem as well as involved societal and environmental issues into introductory science and engineering courses, such as the "*Principles of Engineering*" in the PLTW program.

In the introductory scene of the game, the Mayor of the city welcomes players to join this team, as a consulting engineer, to conduct and report a thorough analysis on the most suitable form of energy for the future of the city. The players are then urged to discuss with different power system experts (game characters) available in the city who can offer valuable information that supports their argument in the report. Upon establishing a meaning role, players can then navigate through different office buildings to collect compelling evidence by conversing with game characters, watching a video about, and taking a quiz, or playing a mini-game on the energy production process they are exploring.

Research indicated that students learn better in a guided learning than discovery learning [7]. However, in a common game environment, players are often left alone with responsibility to explore and to figure out problems themselves. To really bridge the gap between entertaining and education, several metacognitive interventions are carefully embedded into the game environment and activities. To keep players on track with their role duties, a nice task list, called “Road Map” is designed for them to launch through onscreen menu. As shown in Fig. 1, the list clearly presents which tasks have been accomplished and which are yet to be done. More evidence will also appear in this list after individual task is done. For instance, soon after meeting with the Mayor, the player will get the city budget and energy demand, which are ultimately important to the decision presented in his or her report.

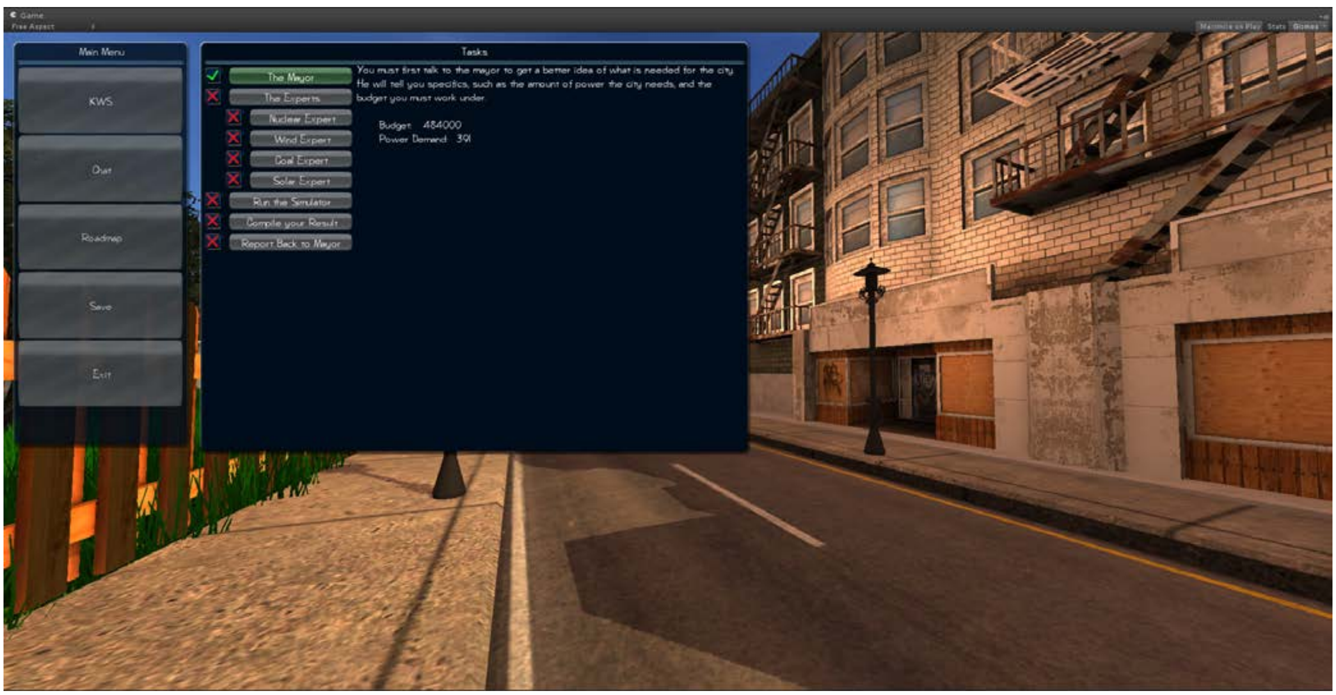

Fig. 1: A Road Map in Power Ville

Learning is a complex cognitive process that imposes motivation, aptitude, and high-level thinking on learners. The more learners are aware of this process, the more they can control, and the better they become as a successful learner. To facilitate students’ self-monitoring and self-regulating their problem-solving in the game, a series of question prompts are designed to activate students’ prior knowledge by asking what they know about a problem (K), to motivate students to think further in-depth by asking what they want to know (W), or to review in retrospect what part of the problem has been resolved (S). This type of intervention, called "KWS" is adapted from a well-known reading strategy, What I **K**now-What I **W**ant to Know-What I Have **L**earned (KWL) [8]. As shown in Fig. 2, the player is prompted with a question of what he or she learned from visiting the coal building.

Fig. 2: A prompt of questions in the game

The crux of a *SustainCity* is to create the smallest ecological footprint, and to produce the lowest quantity of pollution possible. For any chosen energy source, the CO2 emissions and smog-causing pollutants to be created might be different. As we know, increased instances of smog will raise levels of illness among citizens and keep them from work (which costs the player money). And increased carbon emissions could result in floods, droughts, powerful storms, etc which will also cost money to rebuild the city. So the player has to manage the power resource such that they recognize the costs and trade-offs of their choices. Our game is designed to enable the player visually viewing such impact with a chosen energy source in an interactive simulator. As exemplified in Fig. 3, when the player chooses solar source and provides necessary parameters (e.g., the total energy demands of the city), the simulator displays the potential impact of the solar power generation on the city due to the estimated amount of CO2 emissions and smog-causing pollutants.

To assess the economic costs of a design, the game involves students in computer programming activities. In particular, students interact with an optimization programming tool shown in Fig. 4 by providing the collected evidence, and choosing proper logic operators to ensure the chosen energy source meeting certain electricity demand at the lowest cost. The game becomes even fun when students play with their on-line group members where ideas and knowledge are shared as shown in Fig. 5.

Fig. 3: Simulation of solar energy

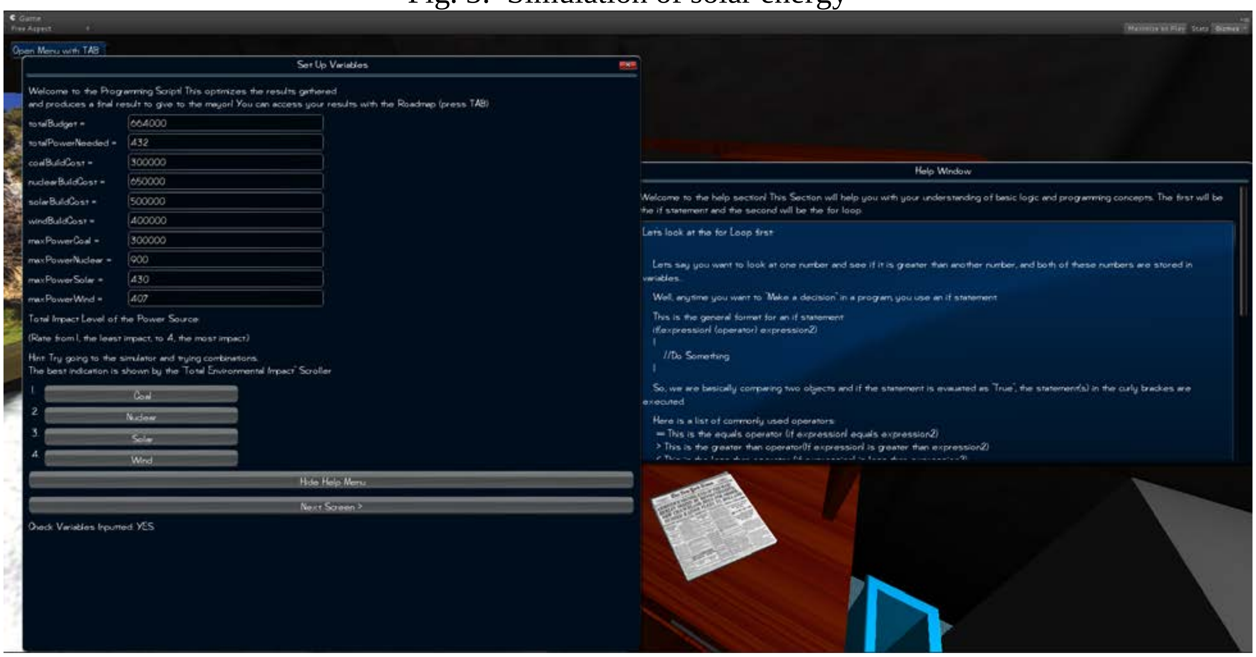

Fig. 4: GUI for optimization programming

<u>Game 2: ThermoPower</u> – There exists a strong impact of engineering decisions on the availability and sustainability of energy resources. This impact can be investigated through the study of specific thermal engineering problems. Using virtual environment platform, this game allows students to identify key thermal processes and their ability to implement conduction, convection, and radiation modes of heat transfer. In particular, students will be able to (a) implement the laws of thermodynamics in the conversion of coal to electricity in form of a C++/JAVA program module. (b) analyze the thermal processes involved in transforming the heat from combustion of the coal to produce steam leading to production of electricity (c) visualize the industrial and residential electricity demands of the city being met with the thermal process. The laws of thermodynamics are considered to be instrumental in providing insights into environmental problems associated with energy utilization due to the impact on environmental

quality and natural ecosystem. Thus, this game allows students to understand the relations between environmental impact and thermodynamics, which is an appropriate match to the contents of the "*Principles of Engineering*" course in the PLTW curriculum.

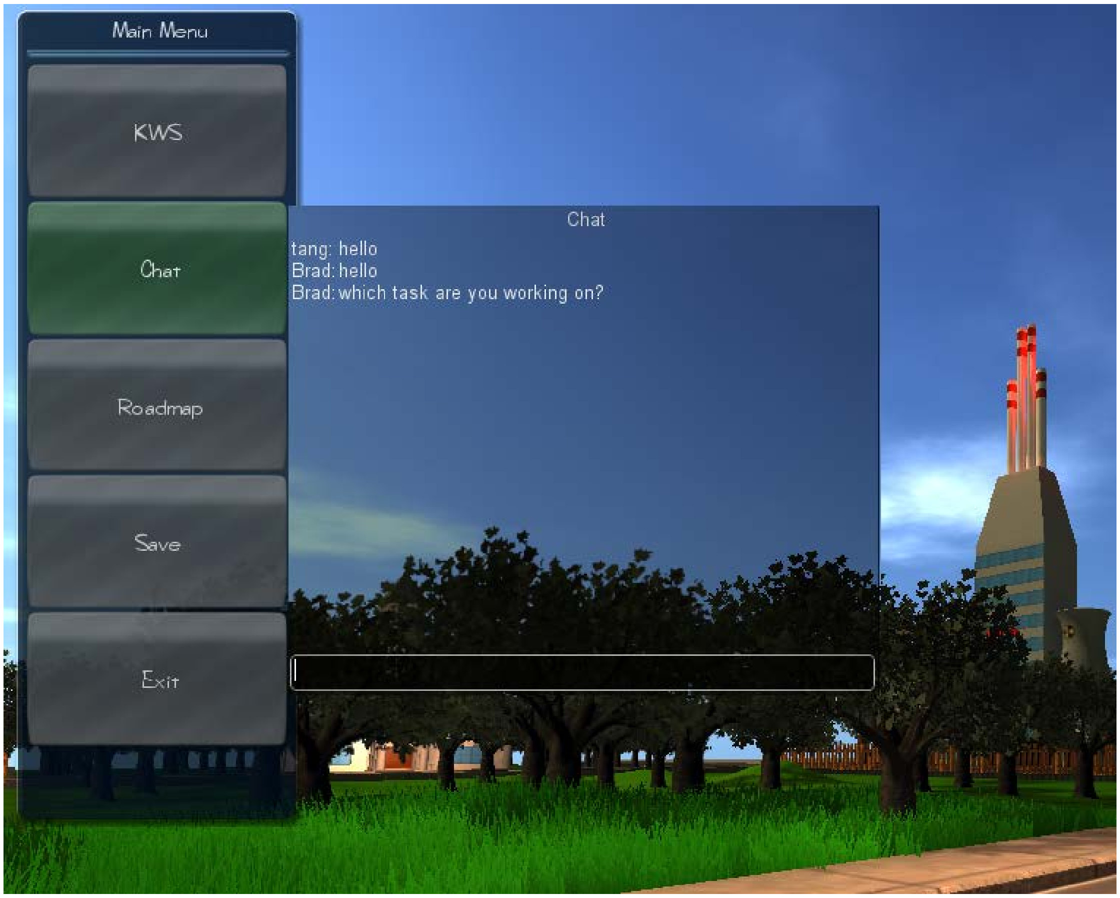

Fig. 5: Chatting enabled in the game

Game 3- The Mystery of Traffic Lights- Automatic traffic light is a typical engineering invention that made the lives of common people safer and more convenient. For the development of the future *SustainCity*, its design inevitably appears in the agenda of the city master plan and becomes the essential task of this game module. The game invites students to investigate solutions to automatic traffic light control that better fits the future traffic flow of a 4-way intersection. With the capability of importing MultiSim [9] circuit design file with oscilloscope data to validate students' schematic designs and visualizing the simulation results as the responses of traffic lights, the game naturally transforms the digital logic fundamentals to lively concepts that students can associate. Note that MultiSim is the circuit design software adopted by the PLTW program. This game is devoted to sequential circuit design, involving the concepts of finite state machine, state minimization for optimization, as well as the design procedures. It will be piloted in the foundational PLTW course "*Digital Electronics*".

Game 4: Stability– There is a strong interrelationship between success and failure in engineering. When engineers properly anticipate the possible failure modes of a structure or system, they can obviate them by design [10]. This game actually explores such nature of design – success through failure, providing students a virtual environment to build bridges with constraints. In particular, students will be able to (a) use CAD software *Inventor* [11] imported into the game interface for 3D bridge design, (b) analyze the structure impact of gravity and other loading effects on a bridge, and (c) visualize bridge collapses resulting from their impropriate choices of bridge spans, materials, and/or forms with a given gravity loading condition. Connecting those failures to the real tragedies in the world, such as Minneapolis bridge collapse in 2007 [12] and Tacoma Narrow bridge collapse in 1940 [13], brings professional ethics into the game as well. This game project fits nicely to the core of the "*Civil Engineering and Architecture*" course in the PLTW curriculum.

Game 5: BioEnergy- The consumption habits of modern consumer lifestyles are causing a huge worldwide waste problem due to overfilled local landfill capacities, which has a devastating impact on ecosystems and cultures throughout the world. In the field of biofuels engineering, there have been successful attempts to recycle waste by generating electricity from landfill waste and pollution. This game explores the potential of the waste to energy technology in generating electricity and the resultant positive effects on the environment. Specifically, the game allows students to (a) use Biofuel Energy Systems Simulator (BESS) [14] to implement the biochemical conversion process involved in the energy conversion of organic material from waste products; (b) perform energy analysis and efficiency and emission analysis by computing net energy yield and net carbon dioxide, respectively, and trace greenhouse gases and global warming potential; and (c) visualize the environmental impact on the city by adopting biofuels for energy production. This game project fits nicely to the "*Biotechnical Engineering*" course in the PLTW curriculum.

CONCLUSION

A repository of VR games in the context of sustainable city design is being developed. The games are rich in (a) visual representation of science and engineering concepts that are not possible in pencil-and-paper formats; (b) ample interactions with the virtual environment as well as other content learners; and (c) unprecedented access to learning resources that are not limited in time and space. Those features blend informal and formal learning, enhancing, but more importantly enabling life-long science and engineering discovery that might not have been possible in the past.

ACKNOWLEDGMENT

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