A GAME-BASED LABORATORY FOR GEAR DESIGN

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Abstract

Recent research indicates that 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 participants, unknown outcomes as well as elements of competition and chance. Taking advantage of game technology for offering truly immersive and interactive learning experiences has now become a real possibility. Game-based educational environments involve synchronous student interaction mediated through a computer network, and they benefit the students by stimulating the different modalities of learning, i.e. visual, audio, read/write and kinesthetic.

This paper presents the development of a game-based virtual laboratory environment for gear train design, which goes beyond static demonstrations or conventional computer simulations. This virtual laboratory environment provides the students with the flexibility to perform many experiments related to the fundamental law of gearing and the concept of planetary gear motion. In this virtual laboratory environment, the students, the instructor and the teaching assistant are represented by and interact as virtual characters (avatars). The scripted scenario for the laboratory exercise was piloted in the Fall 2010 semester in 'ME 358 Machine Dynamics and Mechanisms', a junior-level course for mechanical engineering majors. Assessment tools such as pre- and post-experiment tests are an integral part of the game-based laboratory environment and form the basis for providing different levels of support to the students at every step of the laboratory exercise. Furthermore, the game environment can be equipped with functionality for monitoring the students' progress and learning outcomes, thus enabling skill-based assessment.

Introduction

Having grown up with a variety of digital technologies, today's students have been described as 'Digital Students' or 'Net Generation' [1,2]. The internet and advanced communication technologies have had a significant influence on their entire lives, including on how they learn. Today's students prefer learning experiences that are digital, connected, experiential, immediate and social [3]. They appear to prefer learning-by-doing rather than learning-by-listening and often choose to study in groups [4]. Therefore, the traditional classroom, teacher, textbooks and blackboard can no longer satisfy the needs of today's students who have grown up with digital technology and computer games. As technology is becoming more global and affordable, academic institutions are finding opportunities to deliver information and services in multiple formats and to multiple devices such as video and audio tapes, email, facsimile, audio and video conferencing, online applications over the Internet, etc. The virtual laboratory environment presented here creates new social and cultural worlds that help students learn by integrating thinking, social interaction and technology.

In recent years, educational researchers have paid more attention to computer games because games are organized around doing and the participants learn through a grammar of doing and being [5,6,7]. 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 tools of powerful learning environments. Games can provide the motivation to learn, thus increasing the likelihood that the desired learning outcomes will be achieved. Many students are highly accustomed to and knowledgeable about playing electronic and computer games, and educational researchers found that games are educational as well as interesting and engaging. These properties offer significant potential for educational contexts that enhance the classroom thinking, problem solving and learning process.

Over the last several years, academic institutions as well as private training and education companies have started to explore the potential of commercially available multi-player computer game engines for the development of virtual environments for instructional purposes. Massively multiplayer online games (MMOGs) provide new ways of knowing, doing, being and caring to support the learning process in the context of rich virtual environments [8]. A number of studies have provided insight into the relationship between video games and learning. It was found that MMOGs can be a form of problem-based learning (PBL) and include all PBL characteristics [9]. MMOGs 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. Both MMOGs and PLB are experiential, collaborative, active and learner-centric. Taking advantage of these favorable characteristics, an existing game engine can be utilized as a means for creating educational laboratory tools that we expect will make it easier for students to learn in an engaging manner. The virtual laboratory environment presented here involves synchronous student interaction through a computer network and benefits the students by stimulating the different modalities of learning, i.e. visual, audio, read/write and kinesthetic. By utilizing a commercial game engine with its vast set of built-in functions as the framework for creating an interactive virtual laboratory environment, the continued advances in game technology are leveraged and the system development efforts can thus be focused more on implementing effective pedagogies.

Achieving a sense of immersion by the students and interactive collaboration among them are two of the main goals being pursued in exploring new types of educational laboratory experiments as alternatives or complements to traditional hands-on experiments. A virtual laboratory environment has been created at Stevens Institute of Technology (SIT). This immersive interactive laboratory environment is based on ‘Source’ [10], a commercial multi-player computer game engine. The prototype system implemented so far allows the students to collaboratively assemble an experimental setup within the game environment. Then, the students can run remote and/or virtual experiments to collect experimental data for subsequent analysis. The scripted scenario [11] for the first laboratory exercise was piloted in the Fall 2007 semester in ‘ME 358 Machine Dynamics and Mechanisms’, a junior level course for mechanical engineering majors at SIT [12]. The laboratory exercise involved an industrial plant emulator designed for experiments with different rotating bodies connected by a gear-belt mechanism [13]. The experimental setup allowed students to determine the inertia of the device itself and of weights placed at various locations within the mechanism as well as to experiment with different gear ratios and belt stiffnesses.

The purpose of this paper is to present another virtual experiment and asses its effectiveness as a supplementary learning tool for teaching the fundamental law of gearing and the concept of the motion of planetary gears. Knowledge tests were given to the students before and after experiencing the virtual learning environment, respectively. The comparison and analysis of the knowledge test results were used to evaluate the learning effectiveness of the developed game-based laboratory for gear design. In addition, 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.

Pilot Implementation

General Course Description

'ME 358 Machine Dynamics and Mechanisms' is a mandatory junior-level course in the undergraduate mechanical engineering curriculum at SIT [14]. In this course, the principles of kinematics and dynamics are introduced and applied to linkages, cam systems, gear trains, belt and chain drives as well as couplings. The three-credit course consists of lectures, weekly graded homework, several small-scale design projects and a series of laboratory exercises. While the homework and design assignments are carried out individually, the students work in teams on the laboratory exercises, wherein they perform the experimental procedures and then analyze the results and prepare a laboratory report. In the pilot implementation of the game-based laboratory environment during the Fall 2010 semester, thirty two students were enrolled in the class.

Gear Train Laboratory

In many engineering applications, two or more meshing gears are used to transmit motion and power from one shaft to another. Combinations of more than two gears are called gear trains. They become necessary when it is required to obtain large speed ratios within the confines of a small design space. A gear train may consist of spur, helical or bevel gears. Depending upon the arrangement of the gears, the gear train can be a:

1. **Simple gear train:** a series of gears capable of transmitting motions from one gear to another. All gear axes remain fixed relative to the frame and each gear is on a separate shaft as shown in Figure 1a.

2. **Compound gear train:** a series of gears are connected in such a way that two or more gears rotate about a common axis with the same angular velocity as shown in Figure 1b.

3. **Reverted gear train:** the axes of the first and last gears coincide as shown in Figure 1c.

4. **Planetary (or epicyclic) gear train:** multiple gears revolve around a single center gear, which differs from an ordinary gear train by having one axis or multiple axes that are movable relative to the frame as shown in Figure 1d.

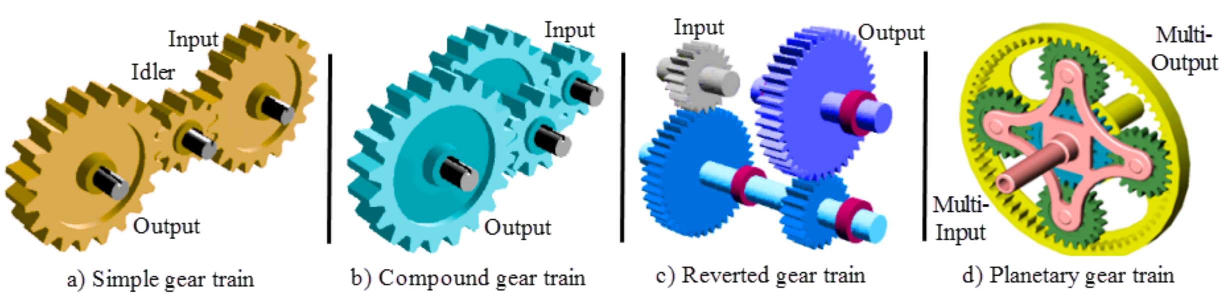

Figure 1: Types of gear trains.

The game-based laboratory for gear train design provides the students with the flexibility to perform many experiments related to the fundamental law of gearing and the concept of planetary gear motion. This virtual environment offers four types of experiments dealing with simple, compound, reverted and planetary gear trains. Each experiment is designed to teach the students how the gear ratio of a gear train alters the output speed and torque of a machine. The students, the instructor and the teaching assistant are represented by and interact as virtual characters (avatars). The apparatus in the virtual gear train laboratory consists of spur gears, helical gears, bevel gears, base, axle shafts and holders as shown in Figure 2. In addition, several spacers and washers are included to allow alignment of the gears and to ensure tight meshing. The experimental capabilities of the virtual environment include:

- Introduction to gear trains, transmission ratios, speeds, etc.
- Assembly of a variety of gear train arrangements that include spur gears, helical gears, worm gears, bevel gears, rack and pinions and compound drives
- Demonstration of the working principles of gear train systems
- Calculation and experimental observation of the angular velocity ratios of gear trains
- Experimental determination of the torque ratios of gear trains
- Calculation of gear train system efficiency

The four types of experiments are meant to demonstrate to the students the various types of gears and their characteristics. In order for gears to mesh in a gear train, they must have the same pitch. Another important concept to be illustrated by the virtual gear experiments is the gear ratio, which allows for the calculation of the relative velocities among various gears of a gear train. As speed increases, the corresponding torque decreases and vice versa. Therefore, it is important to balance these two parameters in designing a gear train for a particular apparatus.

Figure 2: Sample gear train assembly.

Computer Game Engine

Realistic virtual environments have been created using commercial game engines in various contexts. A game engine is the 'brain' of a computer game. In the immersive collaborative virtual laboratory environment developed at SIT [15], the 'Source' game engine [10] was selected, which is one of the commercial game engines that is widely distributed and commonly used to develop massively multiplayer online role playing games. It provides all functions needed to develop a virtual laboratory environment. Furthermore, it has extensive support included in the form of the associated Software Development Kit (SDK) [16], e.g. the 'Hammer' editor and the game engine's source code. All physics simulations are handled by the Havoc physics engine [17]. It allows for realistic interactions between the objects in the virtual world. The experimental equipment was implemented using custom models, and the custom model primitives were created using third-party 3-D modeling software such as 3ds Max and SolidWorks. Custom models were extremely useful in implementing the virtual laboratory, as scripts can be written to define their behavior.

A number of predefined scenarios were scripted. They exercise the students' problem solving skills by mimicking typical problems that might occur when carrying out actual hands-on experiments. In addition, the experimental scripts imbedded within the virtual laboratory system allow one to monitor the 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 as shown in Figure 3.

Game-based Experimental Setup and Procedure

Before conducting the game-based experiment, the students were handed out an experiment scenario as a tutorial in order to introduce them to the capabilities of the laboratory environment and to inform them about how to log into the experiment webpage, how to customize their 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 laboratory system and how to get

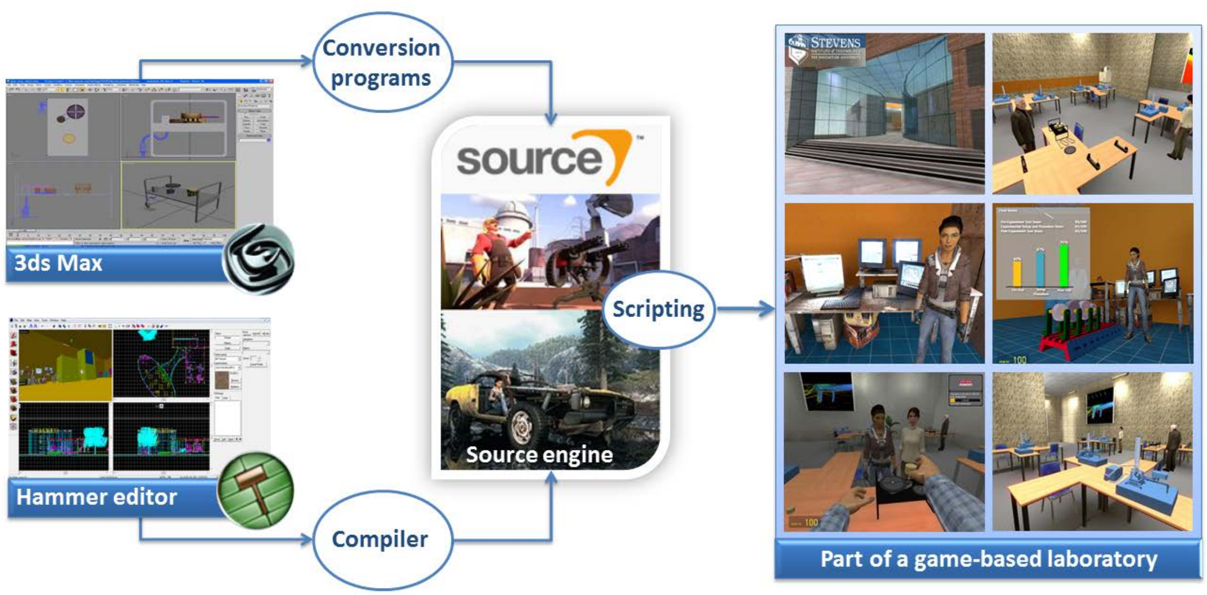

Figure 3: Development of a game-based laboratory environment.

feedback from the instructor (the developers and a TA were present during the pilot). While most of the training sessions for the student groups lasted approximately half an hour, 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 laboratory environment and to the specific experimental setup, the students were divided into groups to conduct the actual experiment. Each group consisted of three students, and each student was placed in a different room. After selecting a particular experiment, the students first had to sign in on the attendance sheet, go through the laboratory manual and then enter the virtual laboratory for performing the experiment (see Figure 4).

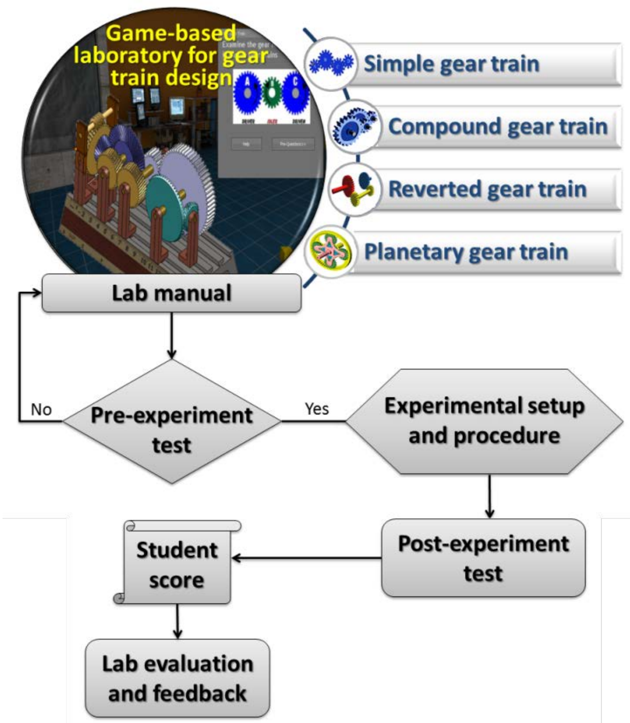

Figure 4: Flow chart for game-based laboratory procedure.

At the beginning of the experiment, after a brief introduction, the game-based laboratory system administers a simple pre-experiment test to the students [18]. For the students who failed the test the virtual laboratory exercise is terminated, and those students need to go through the laboratory manual again. On the other hand, the students who passed the pre-experiment test can then proceed further. The laboratory system offers input options related to the experiment, the students select a particular input configuration (gears, shafts, holders, base, etc.) and proceed to performing the experimental procedure. After the experimental results (gear ratio, speed, torque, etc.) have been displayed, the students may repeat the experiment with a different set of input parameters if they wish, thus enabling them to compare the results of the different configurations with each other. At the end of the virtual experiment, the system administers a post-experiment test to the students. Finally, it provides the students with an opportunity to give feedback regarding the game-based laboratory environment in general, its control and navigation, ease of use, the students' perceived learning and feel of immersion, and other aspects. This user feedback is considered very important for future improvements of the existing virtual laboratory environment.

Pre-experiment test

The main purpose of the pre-experiment test is to assess the conceptual knowledge of the students and their level of preparedness for the laboratory exercise to be conducted and to provide the basis for a comparison with the post-experiment test administered after the laboratory exercise. In the pilot implementation, the results of the pre-experiment test highlighted the areas where the students had the most difficulties and also informed the instructor about the subject areas where they needed additional or remedial instruction. The pre-experiment test was conducted in multiple-choice format because of the corresponding ease of administering such tests and analyzing the relevant results (see Figure 5). The test consisted of ten questions on (1) the types of gear trains, (2) the train value, (3) the purpose of simple gear trains, (4) the gear ratio in simple gear trains, (5) the function of an idler gear in a simple gear train, (6) the effect of the idler gear on the gear ratio, (7) the effect of the idler gear on the rotational direction, (8) the effect of the number of idler gears, (9) problem-solving, and (10) real applications of gear trains. The results of the pre-experiment test (see Figure 5) indicated that on average 65% of the answers to the ten questions were correct, with a minimum and maximum 45% and 85%, respectively, for the individual questions.

Game-based Experiment

Upon the completion of the pre-experiment test, the students directed their avatars to the designated virtual laboratory space for the simple gear train experiment. In addition to the handouts with a description of the game scenario that were distributed to the students prior to the laboratory session, each student had laboratory instructions available on their personal tool menu in the virtual laboratory environment. Once all team members were in the virtual laboratory environment, they negotiated the division of the tasks involved in the experimental procedure amongst each other using the integrated instant messaging feature. Each student participated actively in the assembly process of the simple gear train setup as shown in Figure 6. For students that needed additional help (e.g. regarding the order in which the components needed to be assembled or how to pick and place an object), a virtual instructor was available at all times. After assembling the simple gear train experiment, the students were asked to build different experimental setups, including a simple gear train with one idler gear, a simple gear train with an odd number of idler gears and a simple gear train with an even number of idler gears. The group could move to each experimental setup and reconfigure their device with the appropriate gear train types for that experimental setup.

Post-experiment Test

After completing the experimental procedure, the students were given a post-experiment test to assess the learning effectiveness of the virtual experiments. The post-experiment test was intended to measure the improvement of the students' conceptual knowledge after completing the laboratory exercises compared with the state before (see Figure 7). The post-experiment questions were not completely identical but similar to those of the pre-experiment test, and the corresponding levels of difficulty were approximately the same. The main reason for not giving identical pre-

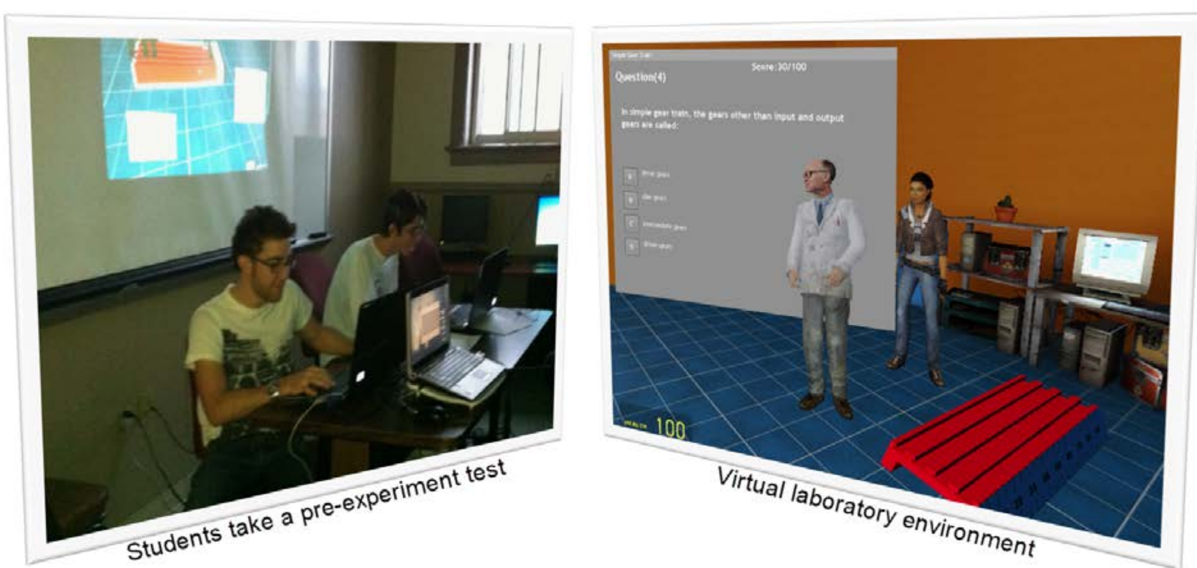

Figure 5: Pre-experiment test to assess the students' conceptual knowledge.

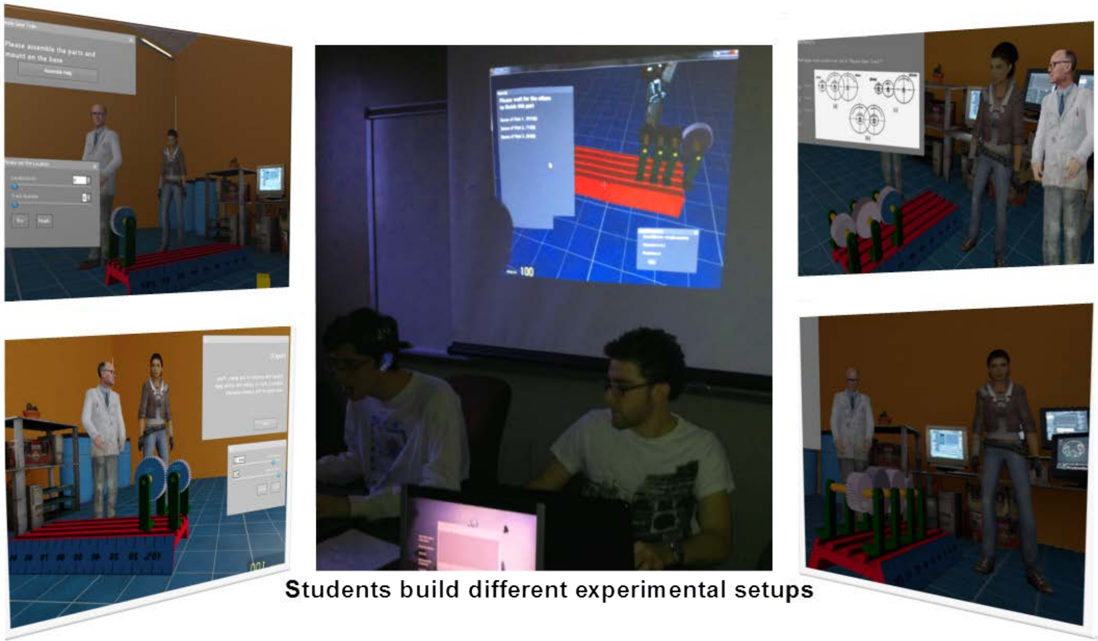

Figure 6: Students (center) and avatars in the virtual laboratory space (left and right).

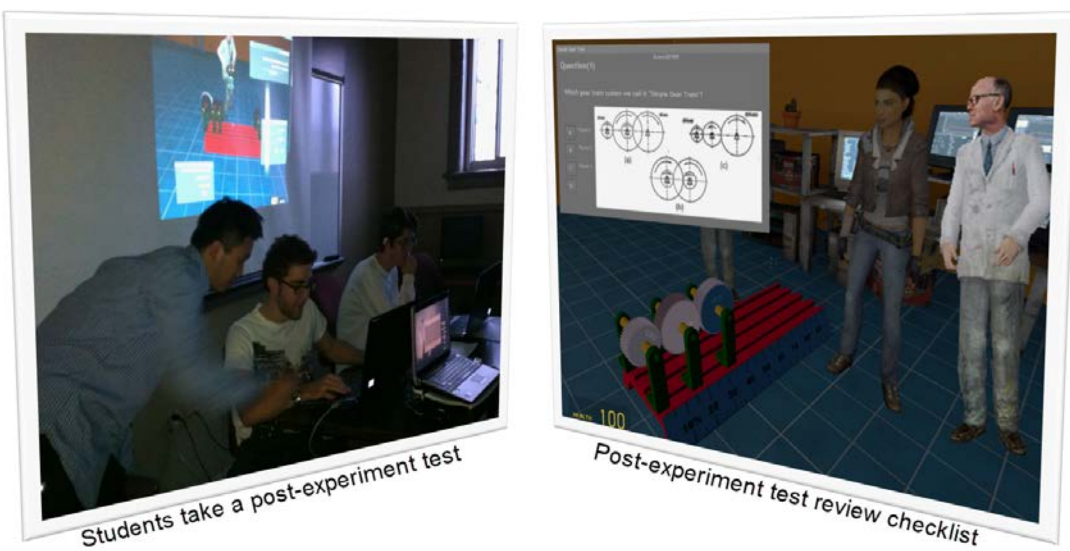

Figure 7: Post-experiment test to assess the learning effectiveness.

experiment and post-experiment questions was to eliminate the effect of short term memorization of the answers. The post-experiment test consisted of ten questions on (1) the distinction between different gear trains, (2) the simple gear train output speed, (3) the motion transfer between two meshing gears, (4) the train value, (5) the identification of an idler gear in a simple gear train, (6) the effect of the idler gear on the gear ratio, (7) the effect of the idler gear on the rotational direction, (8) the effect of the number of the idler gears on the rotational direction and output speed, (9) problem-solving, and (10) limitations of simple gear trains.

The results of the post-experiment test showed that the students answered on average 92% of the ten questions correctly (see Figure 8).

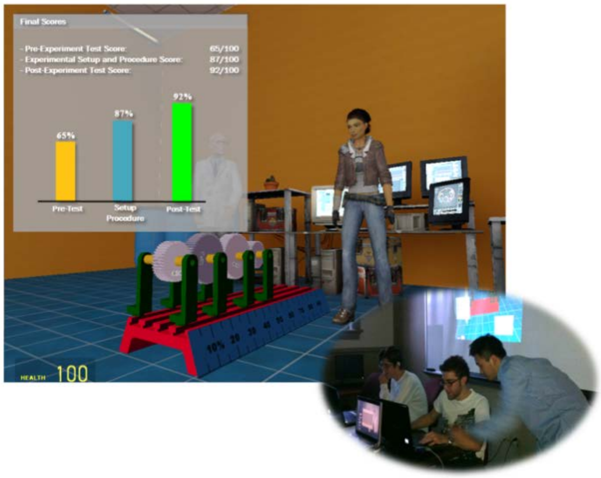

Figure 8: Students' final percentage score.

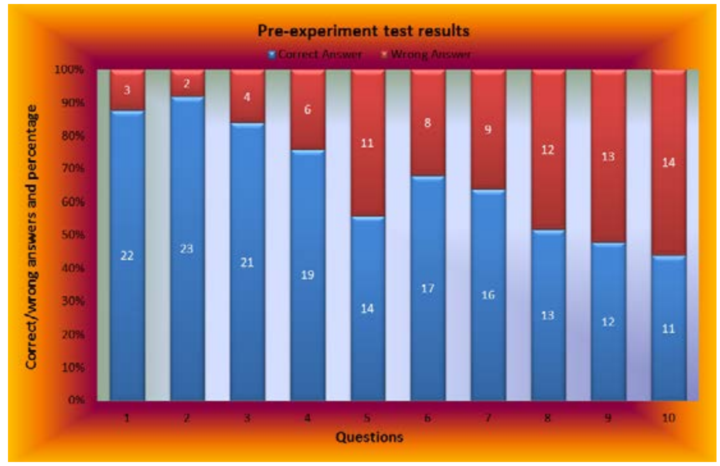

Figure 9: Results of pre-experiment test.

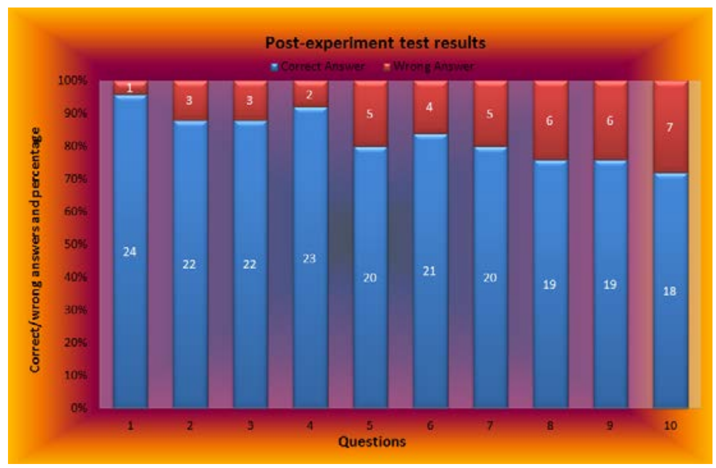

Figure 10: Results of post-experiment test.

Assessment

The purpose of the pre- and post-experiment knowledge tests was to determine whether or not the virtual game-based laboratory had helped the students to improve their understanding and knowledge of the concepts taught in the lecture component of the course and to see whether or not they had improved in the areas where they had problems in the pre-experiment test. Figure 9 summarizes the results of the pre-experiment test for twenty five students. The analysis of this knowledge test revealed that on average 67% of the answers to the ten questions were correct, with a minimum and maximum 45% and 92%, respectively, for the individual questions.

The overall results of the post-experiment test showed that the students on average answered 83% of the questions correctly, with six students giving correct answers to all questions (see Figure 10). Comparing the technical knowledge of the students prior to and after the experiment, they significantly improved their knowledge on the concepts of gear ratio, speed and torque.

During the pilot implementation of the virtual laboratory environment for gear train design, the majority of the students were satisfied in terms of feeling of immersion, ease of use and obviousness, as well as clarity of the instructions. Some minor bugs in the scripts for the assembly of the experimental setups were discovered, but they have been fixed since. However, once the assembly of the experimental setup was completed, the remainder of the experimental procedure was carried out very smoothly. Nevertheless, the students felt an average of 70% satisfaction regarding the reliability of the setups.

A more detailed assessment study of the learning effectiveness of the game-based virtual environment is planned for the Spring 2012 semester. If this more in-depth assessment generates similarly encouraging results, then further extensions of this pilot implementation of the virtual laboratory environment to the design of other gear train types will be considered in the future.

Conclusions

This paper examined the potential of a game-based virtual laboratory environment as an educational tool. Such a game-based virtual laboratory was piloted in the laboratory component of a junior-level undergraduate mechanical engineering course on machine dynamics and mechanisms. In general, the pilot implementation was fairly successful; given that the students improved their knowledge of the concepts taught in the lecture component of the class and expressed general satisfaction with the laboratory approach. The results of this pilot suggest that game-based learning environments have the potential for developing into an educationally viable complement to traditional pedagogical tools and should be further pursued.

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Dr. Sven Esche is a tenured Associate Professor at the Department of Mechanical Engineering at Stevens Institute of Technology. He received a Diploma in Applied Mechanics in 1989 from Chemnitz University of Technology, Germany, and was awarded M.S. and Ph.D. degrees from the Department of Mechanical Engineering at The Ohio State University in 1994 and 1997, respectively. He teaches both undergraduate and graduate courses related to mechanisms and machine dynamics, integrated product development, solid mechanics and plasticity theory, structural design and analysis, engineering analysis and finite element methods and has interests in remote laboratories, project-based learning and student learning assessment.
His research is in the areas of remote sensing and control with applications to remote experimentation as well as modeling of microstructure changes in metal forming processes. He publishes regularly in peer-reviewed conference proceedings and scientific journals. At the 2006 ASEE Annual Conference and Exposition in Chicago, USA, he received the Best Paper Award for his article 'A Virtual Laboratory on Fluid Mechanics'.

Dr. Constantin Chassapis received his Bachelors and Masters degrees in Engineering from The City College of New York and his Ph.D. from the City University of New York. He joined the Department of Mechanical Engineering at Stevens Institute of Technology as an Assistant Professor. Having moved through the ranks, he has been serving as department chair since 2001. In 2009, he was also appointed as the Deputy Dean of the School of Engineering and Science. His research interests are in the areas of integrated product and process development, automation, remote sensing and control, and virtual and remote experimentation. His research is multi-disciplinary in nature and integrates mathematical modeling, optimization methods and experimental studies. Through these activities, he has received best paper awards from ASEE's Instrumentation Division and SPE's Injection Molding Division, the distinguished Assistant Professor Award at Stevens, the Outstanding Young Scholar Award from Digital Equipment Corporation and the Tau Beta Pi Academic Excellence award.