PILOTING A GAME-BASED VIRTUAL LEARNING ENVIRONMENT

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Abstract

In a new technological era, where virtual environments and social networks are redefining how students interact with each other and exchange information, alternative and complementary approaches to traditional hands-on laboratories are emerging. Educational interactive virtual learning environments with integrated access to online laboratory experiments have the potential for augmenting the traditional learning process and providing undergraduate engineering students with knowledge and skills suited for the technologically driven present and future.

Such a virtual learning environment has been created for the laboratory component of a junior-level undergraduate mechanical engineering course on mechanisms and machine dynamics. An immersive interactive laboratory experiment developed based on a multi-player computer game engine, which allows the students to collaboratively assemble the experimental setup of an industrial plant emulator within the game environment and subsequently run remote and virtual experiments, was deployed in a pilot implementation. This paper reports on the learning assessment conducted in that pilot. In particular, the evaluation metrics for the virtual learning environment as well as the data on learning effectiveness and student feedback are discussed.

Introduction

Engineering education is transforming rapidly due to ongoing significant advances in computer and Web technologies. The experimental learning theory by Kolb[1] was suggested as an integrative perspective on learning that combines experience, perception, cognition, behavior, etc. Five categories of learning style models[2, 3, 4] have been recommended in the educational literature: sensing/intuitive, visual/verbal, inductive/deductive, active/reflective and sequential/global. Most textbooks and classroom teaching are intuitive, verbal, deductive, reflective and sequential, and thus they do not meet the needs of the second-tier students who are sensing, visual, inductive, active and global learners. Most researchers agree that an important role in current learning structures is played by "collaborative learning", which allows students to exchange information as well as to produce ideas, simplify problems, and resolve tasks. Therefore, engineering educators have been reshaping the undergraduate engineering curricula to respond and adapt to the ever changing nature of engineering practice that is becoming more global, interdisciplinary and influenced by other disciplines such as computer science, information technology, nanotechnology, economics, etc.

Virtual learning environments represent a concept that evolved from computer-based simulations designed for pedagogical purposes. Collaborative and interactive features required in simulations led to the exploration of the incorporation of video game technologies[5] into online academic learning developments. 3D graphic environments allow instructors to teach situations and concepts of the industrial world by immersing students in an interface that provides the required knowledge and experiences. This growing need for interactive learning motivated educational institutions to start investigating online learning methods for improving traditional learning[6, 7, 8]. Virtual learning environments provide certain benefits, such as fast feedback, progress monitoring and a multimedia enriched experience. At the same time, online learning methods brought challenges such as how to accommodate visual, audio, read/write and kinesthetic modes of learning. General guidelines must be established in order to make sure that

- any educational activity to be performed by students via game engines has clearly defined goals,
- the context of the virtual learning environment is within the engineering domain,
- the level of difficulty of the tasks is within the students' current capabilities,
- all learning activity have a meaningful learning effect, the virtual learning environment has a certain variety of choices and provides proper motivation for the students,
- and feedback is used to keep the students motivated and engaged.

Recently, the potential of using gaming tools[9, 10] for educational purposes has begun to be investigated. This trend is motivated by the fact that many students are highly accustomed to and knowledgeable about playing electronic and computer games. Game-based learning is an extension of the problem-based learning paradigm, having all its characteristics plus some additional advantages. Game-based and problem-based learning are both experiential, collaborative, active and learner centric approaches. 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. These game-based simulations will 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. The utilization of 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 gaming technology are leveraged and the system development efforts can thus be focused more on the 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 laboratories as alternatives or complements to traditional hands-on experiments. A virtual learning environment has been created at Stevens Institute of Technology (SIT). This immersive interactive laboratory environment was based on a commercial multi-player computer game engine[11]. 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[12] for a laboratory exercise was piloted in the fall 2007 semester in "ME 358 Mechanisms and Machine Dynamics", a junior level course for mechanical engineering majors at SIT[13]. The laboratory exercise involves an industrial plant emulator designed for experiments with different rotating bodies connected by a gear-belt mechanism. The experimental setup allows 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. This paper presents the pedagogical outcomes of this pilot study. 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. 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 Mechanisms and Machine Dynamics" is a mandatory junior-level course in the undergraduate mechanical engineering curriculum at SIT. 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 compute the results and prepare a laboratory report. In the pilot implementation of the game-based laboratory environment during the fall 2007 semester, 12 students were enrolled in the class.

Traditional Hands-on Laboratory Mode

Among other experiments, the laboratory component of the class comprises several experiments using an industrial plant emulator [14], which in the past were carried out in the traditional hands-on fashion, i.e. with the students being present in the laboratory facility housing the experimental setup and manually operating the equipment. Since only one experimental setup was available, the student groups (typically consisting of three students) reported to the laboratory during a pre-scheduled time slot. After being introduced to the experimental equipment, the students then proceeded to perform the experimental procedure to collect the data, which they stored electronically for the subsequent analysis and reporting outside of the laboratory period. Even though this traditional mode of laboratory operation was still beneficial for the students and improved their understanding of the concepts taught in the lecture component of the class, it required a lot of instructor time for being present in the laboratory with all student groups and did not provide the students with the flexibility to perform the experiments at their own schedule and to potentially re-run them.

Previous Experimental Setup and Procedures

The industrial plant emulator shown in Figure 1 is a system that is designed to teach students the working principles and the underlying theory of gear sets and belt drives. It introduces the students to the modeling of inertia, friction, backlash and stiffness phenomena in machines. The industrial plant emulator setup consists of a drive disk and a load disk, which are connected to each other via a speed reduction unit. Furthermore, the emulator system is equipped with encoders connected to the drive and disturbance motors and a friction brake.

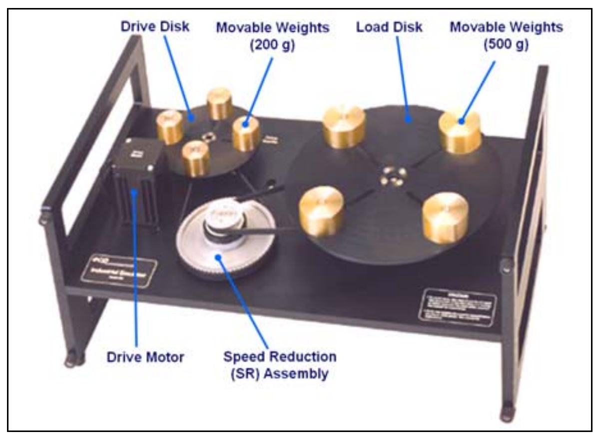

Figure 1: Industrial plant emulator system.

Four sets of experimental procedures are typically performed using this emulator setup. They include the following experiments: the determination of the gear ratio, the measurement of the moment of inertia of the drive train, the determination of the inertia changes due to additional weights attached to the drive and load disks, and the observation of the effects of a flexible belt drive. For these four experiments, repeated assembly and disassembly operations of the emulator setup are required as part of the sequence of experimental tasks, which renders the sequential scheduling of the students group even more cumbersome and slow. In order to overcome these logistical challenges, the emulator setup was later retrofitted with remote access capabilities, and a virtual simulation module was developed, so that the data acquisition could be performed by the students at any time and from anywhere via the Internet. Typically, online experiments (i.e. remote experiments based on actual hardware and virtual experiments representing pure software simulations) only provide the students with numerical output but fail to give them a hands-on experience and are not suited for collaborative work. These shortcomings then motivated the investigation of the possibility of using a commercially available game engine for implementing the immersive collaborative learning environment presented here.

Game-based Experimental Setup and Procedure

Realistic virtual environments have been created using commercial game engines in various contexts. A game engine is the "brain" of computer games. In the immersive collaborative virtual laboratory environment developed at SIT, the students can work collaboratively in teams to perform the various tasks involved in the emulator experiments. The virtual laboratory environment consists of the following three main components: (i) a game-based virtual laboratory facility where the students obtain laboratory instructions, divide the tasks amongst themselves and assemble a virtual experimental setup, (ii) 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 (iii) a virtual laboratory module that the student 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 were handed out an experiment scenario as a tutorial to introducing 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 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 (the developers and a TA were present during the pilot), and finally how to connect to the remote experiment module. 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 learning environment and to the specific experimental setup, the students were given a pre-experiment test to measure their knowledge of the principles and theory underlying the experiment.

Assessment

The main purpose of the pre-experiment test was to assess the conceptual knowledge of the students and their level of preparation for the laboratory to be conducted and to provide the basis for the comparison with the post-experiment test administered after the laboratory exercise. The results of the pre-experiment test highlighted the areas where students had the most difficulties and also informed the instructor about the subject areas where the students 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. It consisted of five questions concerning the concepts of (1) gear ratio, (2) rotational direction, (3) inertia, (4) flexible versus rigid machines, and (5) the effect of weights on the inertia and general performance of machines.

Figure 2 summarizes the results of the pre-experiment test. The analysis of this knowledge test revealed that on average 55% of the answers to the five questions were correct, with a minimum and maximum 20% and 80%, respectively, for the individual questions. The highest percentage of correct answers was achieved in the questions concerning gear ratio (question 1) and gear rotation (question 2).

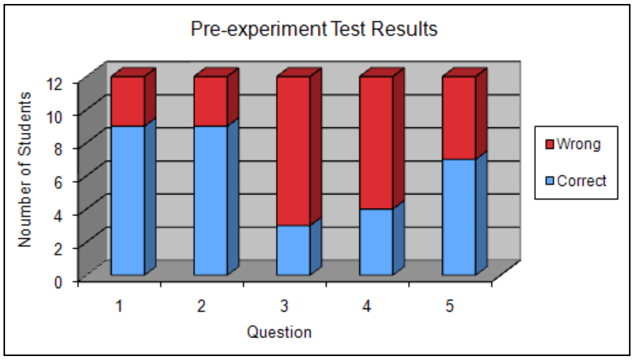

Figure 2: Results of pre-experiment test.

Upon the completion of the pre-experiment test, the students were divided into groups to conduct the game-based experiment. Each group consisted of three students, and each student was placed in a different room. After all students had logged into the game environment, they directed their avatars to the designated virtual laboratory space for the industrial plant emulator 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 industrial plant emulator setup. 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 setting up the emulator, the students launched a remote experiment to collect the experimental output from the physical setup, followed by the simulation of additional experimental procedures where they varied the weights, gear sets and belts.

After completing the experimental procedure, the students were given a post-experiment test to assess the learning effectiveness and a three-part post-experiment questionnaire to collect general feedback. In the knowledge test, the students were asked to answer questions related to the experiment in order to assess their knowledge gained through the experiment. These five technical questions were similar to those in the pre-experiment test. In the questionnaire, the students were asked to evaluate and comment on the general concept of the game-based virtual learning environment.

Section one of the post-experiment questionnaire was designed to obtain feedback on the present state of development of the game-based system as well as on desirable future developments from the point of view of the students. The students were asked to comment on preparatory instruction (question 1), data acquisition (question 2), laboratory report (question 3), teamwork (question 4) and physical presence in the laboratory (question 5). The results are shown in Figure 3.

Based on the analysis of section one of the questionnaire, preparatory instruction and data acquisition were ranked as the most crucial aspects for understanding of the concepts taught in the lecture, whereas laboratory report, team work and physical presence in the laboratory were considered to be of less importance. This result emphasizes the students' believe that performing the experiment in the laboratory is not crucial and thus conducting the experiment online is considered equally effective by the students. Considering the fact that this game-based laboratory was a pilot implementation, it is promising to see that the students did not feel the need for physical presence in the laboratory.

In order to measure the students' level of satisfaction, in section two of the post-experiment questionnaire, the students were

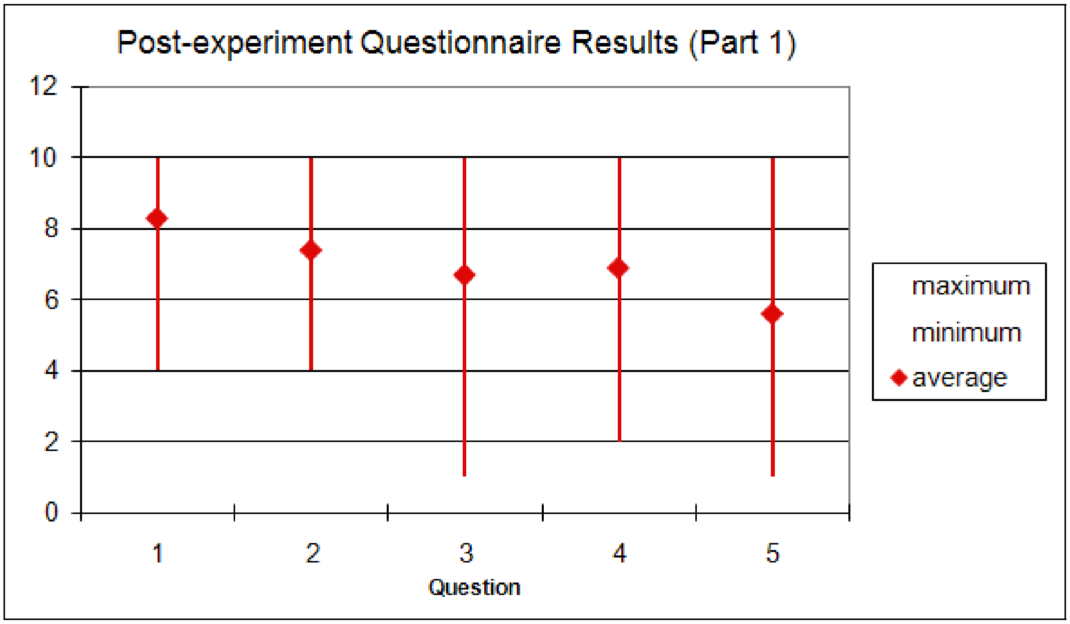

Figure 3: Results of post-experiment questionnaire, part 1.

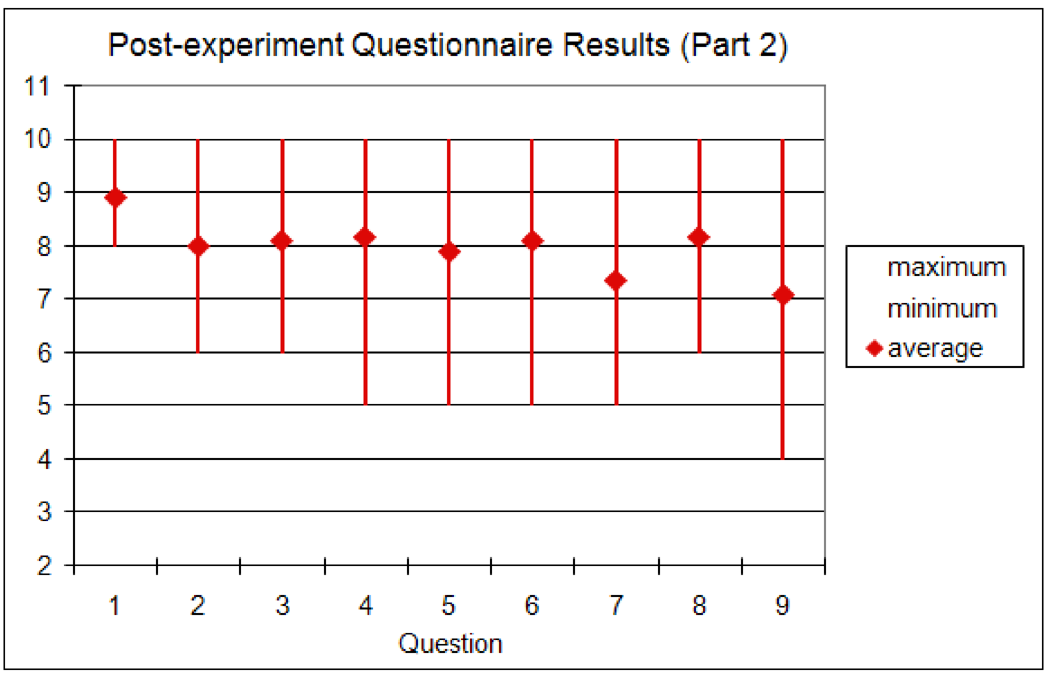

Figure 4: Results of post-experiment questionnaire, part 2.

asked to rank different aspects of the game-based laboratory environment from 1 through 10, with 1 being “not at all helpful” and 10 being “absolutely crucial”. Figure 4 summarizes the corresponding results.

Even though the students had not physically been to the actual laboratory and thus did not get to see the actual physical emulator setup, the average score for overall student satisfaction was 8.9/10 (question 1). The majority of the students were satisfied in terms of feeling of immersion (question 2), ease of use (question 3) and obviousness (question 4), required time (question 5), convenience in scheduling the laboratory sessions (question 6) and clarity of the instructions (question 8). The aspects with the lowest scores were convenience in access (question 7) and reliability of the setups (question 9). Given the fact that this was the pilot implementation, there were small system glitches relating to the setup process for the software. However, once the setup was performed correctly, the remainder of the procedure followed a basic procedure and was carried out very smoothly. Nevertheless, the students felt an average of 71% satisfaction regarding the reliability of the setups.

Section three of the post-test questionnaire solicited student comments, giving them a chance to describe in their own words the specific advantages and disadvantages of the game-based laboratory environment, to provide any specific suggestions for improving the existing system, to comment on whether they thought they would learn more if they were to perform the experiment in the traditional hands-on mode, and finally to decide which additional experiments should be developed in the game-based mode. Below, a summary of the responses is provided:

Specific advantages of the game-based experiment:

- The concept is great; one can perform experiments without worrying about the environmental conditions.
- Best case of technology being introduced into the curriculum; I just like online learning.
- Ease of use and accessibility.
- It created more interest than the traditional boring laboratory experiments.
- One can simulate almost any experiment without having to meet at a specific time.
- No need to be present; flexible scheduling.
- Easy to alter/repair wrong data collection.

Specific disadvantages of the game-based experiment:

- One does not get to feel what the experiment is like physically.
- Not knowing the exact setup of the experiment (e.g. in the game one needs to remove the weights, but one does not know how this works in the real setup).
- Loss of sense of physical meaning behind the experiment.
- Harder to get help with the experiments, especially at non-traditional times.
- Too open ended; one can toss the TA across the classroom.
- Software incompatibility issues.

Specific suggestions to improve the game-based laboratory setup:

- Smoother and more stable control of movement and camera angle.
- Improve user interface.
- Make the experiment setup more realistic / accurate.
- Maybe provide more theoretical background on the purpose of the experiment.
- More licenses for the game-based system to be able to use it on the students’ laptops.
- Virtual experiment needs to be easier to access; VRML is not a very good system.

- Interface is OK, but allow the game modification to access the experimental data for more effectiveness.

Any specific things you would learn in traditional laboratories that you feel you do not learn in a game-based laboratory?

- Not really, except for actually setting up the experiment.
- Direct instruction and Q&A with TA.
- How the physical setup really works.
- How various equipment is used and operated.

Do you have any suggestions for additional experiments that you would like to have made accessible in a game-based laboratory environment?

- Designing aircraft.
- Every laboratory for every class.
- All laboratories at SIT where raw data are collected during the scheduled laboratory time.
- Laboratories where the data acquisition takes a period of time and the students must wait for the results.
- Large scale experiments, like airplane engineering and testing.
- Truss stress/strain experiments.
- All mechanical engineering fluid experiments.

Additional feedback:

- I personally had trouble picking up objects and placing them but I am sure it gets easier the more you play with it.
- The possibilities seem endless, I hope you hook up more labs to it soon.
- Possibly when you have the belt in your hand make it possible to select two points, the if those two points meet the criteria for the specific belt, then the belt would attach there.
- Being able to use the wind tunnel would also be useful in my senior design project, creating the heavy lift cargo plane for the SAE competition.
- Without having built a physical model of an airfoil, I could collect necessary lift and drag data.
- Being able to place each piece by hand rather than using the "tractor beam" may make this easier.

The post-experiment test was intended to measure the improvement of the conceptual knowledge of the students. The post-experiment questions were not completely identical but similar to the pre–experiment questions, and the corresponding levels of difficulty were approximately the same. The main reason for not giving identical pre-experiment and post-experiment questions was to eliminate the effect of short term memorization of the answers. 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 they had improved in the areas where they had problems in the pre–experiment test. The overall results of the post-experiment test showed that the students on average answered 60% of the questions correctly, with two students giving correct answers to all questions (see Figure 5). Comparing the technical knowledge of the students prior to and after the experiment, they significantly improved their knowledge on the concepts of gear rotation (question 2) and flexible versus rigid machines (question 4) and accomplished a slight improvement in the inertia-related question (question 3).

Conclusions

A game-based virtual learning environment for the laboratory component of a junior-level undergraduate mechanical engineering course on mechanisms and machine dynamics was developed and piloted. In general, the pilot implementation was successful. However, based on the students' feedback, several areas for

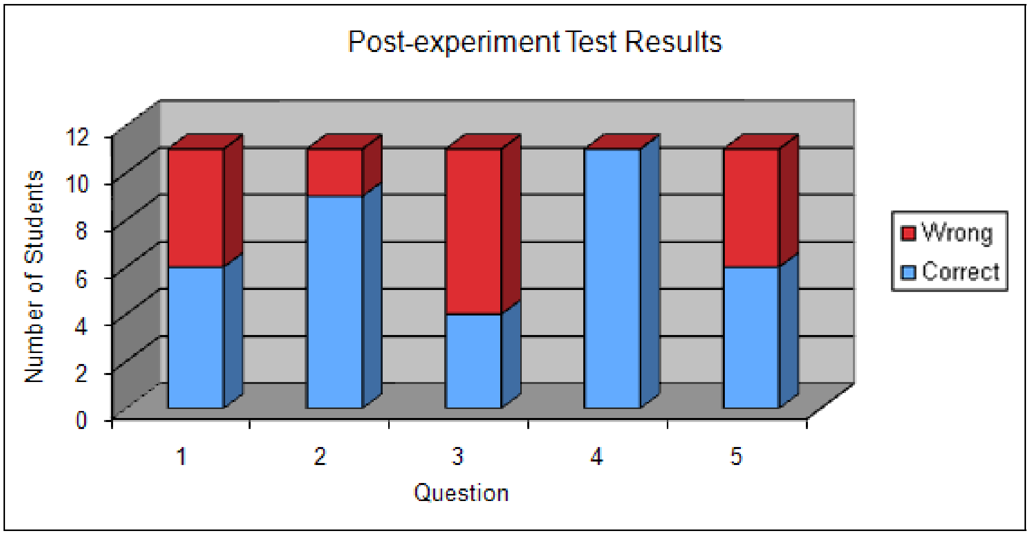

Figure 5: Results of pre-experiment test.

improvement were identified. Using the approach of combining the game-based laboratory environment with remote and virtual experiments, the students are enabled to repeat the laboratory experiments more than once as opposed to having to complete the laboratory procedure during the allotted time as in the traditional hands-on mode. Overall, 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 compliment to traditional pedagogical tools and should be further pursued.

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