Evaluation of a video game adaptation for mechanical engineering educational laboratories

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Abstract -- Nowadays, an increasing number of video games enable third-party designers to redesign the original games. By adapting video games and taking advantage of their technical features such as 3D effects, audio, Internet communications, etc., educators can deliver certain course materials through these games. Meanwhile, whether, or to what extent, these educational adaptations enhance the students' learning effectiveness is still the subject of research.

In a mechanical engineering educational laboratory, students may face theories or concepts that they have just learned, mechanical devices that they have not previously used as well as collaborative tasks that they have not been assigned before. While traditional educational laboratories may be constrained by hardware, an adaptation of video games may help the students. An immersive gear train laboratory has been developed in which a popular first-person shooting game, Garry's Mod, was adapted.

In this paper, an evaluation of this adaptation is presented from both a laboratory performance perspective and a learning effectiveness perspective. 110 undergraduate students who took the junior-level "Machine Dynamics and Mechanisms" course in the authors' university performed video game-based gear train laboratory exercises immediately after attending the lectures and completing the homework related to the chapter on gear design. They were required to form groups for completing the laboratory tasks in the video game environment, where their operations were recorded. Short tests were given to the students before and after the laboratory exercises in order to assess whether their understanding of the course material was enhanced by the laboratory exercises. It was found that the students' performance in the laboratory exercises is more likely to be affected by their understanding of the course material than by their familiarity with first-person shooting games. From these tests, it was observed that most students showed an improvement in understanding the course contents after completing the laboratory exercises.

Keywords – virtual educational laboratory; learning effectiveness evaluation; student collaboration evaluation

I. Introduction

The advancement of computer technology and the rapid expansion of online education brought new challenges for engineering educational laboratories [1]. Besides traditional hands-on laboratories, many remote laboratories (for instance, [2], [3], [4]) and simulated laboratories (for instance, [5], [6], [7]) have been tested by engineering educators.

Possibilities for applying virtual reality technology to provide simulated educational laboratories with immersive experiences are also discussed (for instance, [8], [9], [10], [11]). These virtual laboratories are often based on 3rd party virtual reality engines, for instance, game engines, which not only can be adapted to provide an educational virtual laboratory environment, but also enable educational laboratory designers to flexibly assign laboratory tasks [12]. In addition, simulated virtual reality laboratories are able to connect students with state-of-the-art engineering innovations in scenarios where the experiment conditions are complicated and the required apparatus is expensive [13], [14]. Many researchers have discussed whether these new forms of laboratories are as effective as traditional hands-on laboratories in fulfilling different engineering laboratory objectives, such as enhancing learning outcomes, training for collaboration, etc. [15], [16], [17], [18]. While the research in earlier years showed that the learning outcomes in hands-on laboratories were better than those in the other forms, later research indicated that, because of the improvements of educational designers' computer skills, all forms of laboratories showed advantages and disadvantages.

The authors of this paper developed a virtual laboratory system by adapting a video game [19]. In previous research conducted, it had been shown that the students' background in gaming is not necessary for using the virtual laboratory system. It had also been demonstrated that, although certain students encountered some difficulties that were caused by the operation of the virtual laboratory system at the beginning of the laboratory exercises, they were able to gradually get used to the operation and complete all laboratory tasks. In this paper, an evaluation of the learning effectiveness and the students' collaboration are discussed.

II. Virtual laboratories by video game adaptation

A. General description

The technical details of the adaptation of Garry's Mod, a popular "sandbox" game for players to simulate their creative designs, for constructing an educational virtual laboratory platform, could be found in the authors' previous publications [20], [21]. The virtual laboratories have the following features:

1. Immersion into the simulated environment: students are enabled to navigate in a virtual environment, in which their avatars, the laboratory room and the laboratory apparatus are presented. Students can use mouse and keyboard to navigate and operate the laboratory apparatus. The mouse and keyboard operation is the same as that in most first-person-shooting games.

2. Collaboration among students: students, despite of being physically separated, can collaborate through the virtual laboratory, i.e. they can collaboratively work on the same tasks.

In addition, virtual laboratories are able to automatically record the students' activities, which could not be monitored in traditional laboratories. Through this functionality, teaching staff can better evaluate the students' learning and participation in the laboratory exercises.

B. Tasks for simple gear train laboratory and planetary gear train laboratory

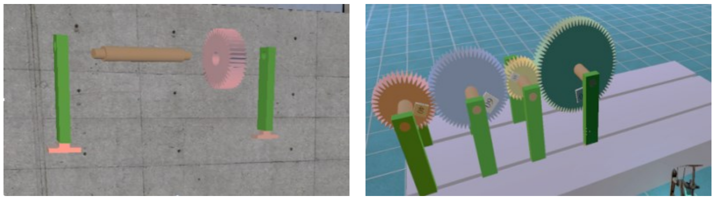

Figure 1: Tasks in simple gear train laboratory exercise

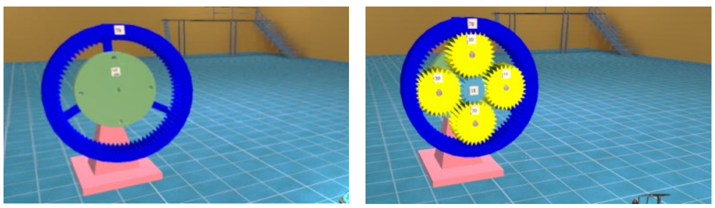

Figure 2: Tasks in planetary gear train laboratory exercise

In the simple gear train laboratory exercise, the students are required to design a simple gear train with specified speed ratio and output direction. The virtual laboratory provides mechanical parts, such as shaft, shaft holder, gears with different number of teeth, etc., for them to use. Since this is their first virtual laboratory exercise, the students must run through a short tutorial that teaches them how to use the virtual laboratory.

Figure 1 shows the tasks for the students in the simple gear train laboratory exercise. The students must first select and mount a gear to a shaft, then mount the shaft on the shaft holders, and adjust the center distance of different gears to form a simple gear train. The students are expected to enhance their understanding of the key concepts of gears and gear trains, such as module, pitch diameter, and idler gears, etc., during this laboratory exercise.

After the students have completed the simple gear train laboratory exercise, a planetary gear train laboratory exercise is administered which involves fewer operations. However, the configurations and kinematics of planetary gear trains are more complicated than those of simple gear trains.

Figure 2 shows the tasks for planetary gear train laboratory exercise. The students are given gears with different dimensions, and they must select compatible gears in order to successfully build a planetary gear train. The students' understanding of planetary gear train members, the configurations of planetary gear trains, and the velocity/torque ratio of different configurations are expected to be enhanced.

III. Evaluation methods

A. Participants and context

Two educational laboratory exercises, one for simple gear train education and the other for planetary gear train education, were arranged for evaluation. The students who take the required junior-level undergraduate course "Machine Dynamics and Mechanisms" are asked to conduct these two virtual laboratory exercises, along with traditional hands-on laboratory exercises. The virtual laboratory exercises are designed to enhance the students' understanding of machine dynamics theories, most of which are in the form of equations that they learn in the lectures.

108 students performed the simple gear train laboratory exercise. 52 groups with 2 members each were formed. The remaining 4 students worked individually. 110 students conducted the planetary gear train laboratory exercise. 92 of them formed 46 groups of 2 and 18 students worked individually. The students who worked in a group were physically located in two separate rooms so that they could not directly talk with each other but rather could only communicate through the virtual laboratory.

B. Procedure of evaluations

Due to limited number of available Garry's Mod licenses, the laboratory exercises were conducted outside of the regular laboratory class times by appointment. The timeline of this learning outcomes evaluation was arranged as listed in Table 1. Compared with previous evaluations, pre- and post-laboratory tests are added for each laboratory.

Table 1: Timeline of evaluation

Week of the semester	Activity
7	Taking videogame background survey and grouping
8-9	Attending gear train lectures and completing gear chapter homework
10-11	Performing simple gear train laboratory exercise
12-13	Performing planetary gear train laboratory exercise
14	Taking evaluation survey

C. Measures

The learning outcomes of the virtual laboratories were measured by the integration of

1. the students' scores in pre-laboratory tests and post-laboratory tests
2. the students' final exam scores for the gear chapter

The pre-and post-laboratory tests, consisting of 6 multiple choices questions each, were given immediately before and after each laboratory exercise. These questions are designed to evaluate the students' understanding of very basic concepts of gear trains. In addition, in order to better evaluate the students' knowledge gain from the laboratory exercises, the pre- and post-laboratory tests are designed based on the same set of coursecovered knowledge topics, with different questions as well as in altered orders of topics.

Table 2 and Table 3 in section IV (B) list the topic of each question in both laboratory exercises together with the corresponding results.

IV. Evaluation of learning effectiveness

A. Overall pre- and post-laboratory test outcomes

The learning outcomes of these two laboratory exercises were measured by the pre- and post-laboratory tests. As mentioned earlier, each test contained 6 multiple choice questions. Each question counted for 1 point. Figure 3 shows the mean scores and standard deviations of all tests.

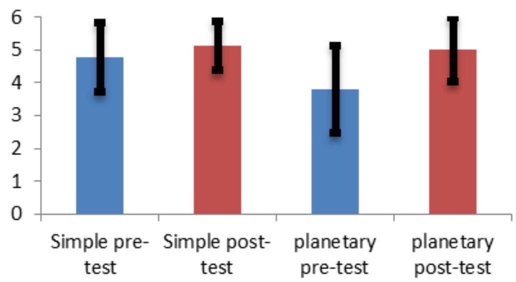

Figure 3: Means and standard deviations of pre- and post-laboratory test scores

From the tests of 108 students who performed the simple gear train laboratory exercise, the average scores of pre- and post-laboratory tests were 4.79 and 5.12 (representing a 6.9% increase), respectively; the standard deviations were 1.07 and 0.74 (representing a 30.8% decrease), respectively. There were 110 students who performed the planetary gear train laboratory exercise. The average score increased from 3.80 in the pre-laboratory test to 5.01 in the post-laboratory test (a 31.8% increase); while the standard deviation decreased from 1.33 to 0.97 (a 27.1% decrease). Therefore, from the test statistics, it can be seen that the students' understanding of the required topics was enhanced by the laboratory exercises.

B. Percentage of correct answers for each topics

Because the pre- and post- tests of each laboratory share the same topics with different questions, by evaluating the results from each topic, the learning effectiveness of the laboratory exercises can be analyzed.

Table 2 lists all topics of the tests of the simple gear train laboratory exercise. From the table, it can be noted that in all topics, except in topic 2, more students gave more correct answer in the post-test than in the pre-test. However, it was also found that only 46.30% of the students were able to correctly answer the topic-2 question in the post-test while 93.52% students could answer this topic question correctly in the pre-test. There are two possible reasons for this drop. First of all, topic 2 is not directly addressed by the laboratory exercises. The question is about the definition and the components of the simple gear train, which is only explained in the lecture. Secondly, a pitfall choice in the post-test, stating "all centers of the axles of a simple gear train must fall on a straight line" misled many students. Because in the laboratory exercise, the students were required to design a simple gear train with all the center of axles being on a straight line, many students fell into this pitfall by selecting this choice. Table 3 lists the topics for the planetary gear train laboratory tests as well as the corresponding results. It can be seen that the number of correct answers by the students increased in each of the topics.

Table 2: Test question topics for simple gear train laboratory and results

Topic Number	Topic	Question # in pre-test	Question # in post-test	Pre-test correct %	Post-test correct %
1	Definition of gear module	1	3	82.41%	100.00%
2	Definition and members of simple gear train	2	4	93.52%	46.30%
3	Center distance between input/output gears	3	1	83.33%	100.00%
4	Functionalities of idler gears	4	2	67.59%	100.00%
5	Computation of gear ratios for simple gear train	5	6	63.89%	93.52%
6	Input/output velocity direction change with respect to the number of idler gears	6	5	85.19%	94.44%

Table 3: Test question topics for planetary gear train laboratory and results

Topic Number	Topic	Question # in pre-test	Question # in post-test	Pre-test correct %	Post-test correct %
1	Members of planet gear train	1	5	79.09%	83.64%
2	Speed ratio under different configurations	2	3	60.91%	92.73%
3	Dimensions of members of planet gear train	3	2	61.82%	66.36%
4	Relationship between torque ratio and speed ratio	4	1	36.36%	99.09%
5	Input/output velocity direction change under six configurations	5	4	66.36%	67.27%
6	Input/output gears change under six configurations	6	6	75.45%	91.82%

C. Evaluation of effect of virtual laboratories on students' final exam grade on gear chapter

In the author's institution, the course "Machine Dynamics and Mechanisms" is offered on a semester basis. The virtual laboratory exercises that were evaluated in this paper were offered in the spring semester of 2015. In the fall semester of 2015, these virtual laboratory exercises were not administered. Instead, paper-based practice laboratory exercises were offered. With the same course contents, a similar set of homework assignments, the same teaching staff, and similar examination questions, the effect of the virtual laboratory exercises could be evaluated**.** However, because many uncontrollable factors existed, such as detailed course schedule, students' background (although the students were from the same department, in the spring semester, most students were in their junior year while in the fall semester, most were in their senior year), etc., such a comparison of the effect of the virtual laboratory exercises on the students' final exam performance needs further evaluation.

In the final exams of both semesters, two 20-point questions, with one being about simple gear trains and the other being about planetary gear trains, were asked. Although the question contents were different, the topics tested were the same. Figure 4 demonstrates the means and standard deviations for the students' final exam grades on the gear chapter. 35 students in the fall semester, who did not conduct the virtual laboratory exercises, on average achieved a total score of 30.69 on the 2 questions, with a standard deviation of 9.48. 108 students from the spring semester, who performed both laboratory exercises, on average obtained a score of 32.92, with a standard deviation of 6.58. From the increased average score and decreased standard deviation, it can be concluded that the virtual laboratory exercises have a positive effect on improving the students' understanding of gear train concepts, and thus, compared to students who were not offered the virtual laboratory exercises, their final exam grades improved.

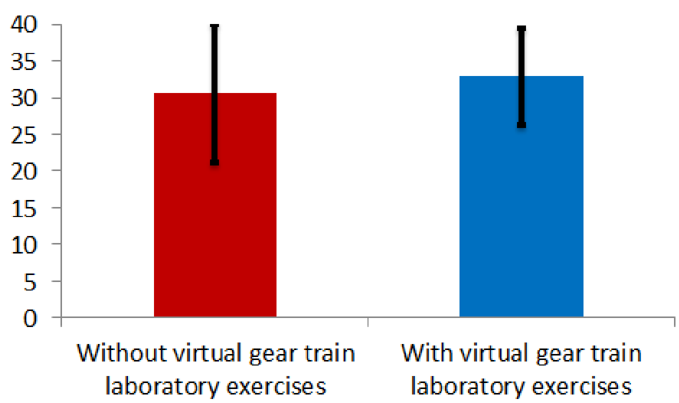

Figure 4: Comparison of means and standard deviations for final exam grade on gear chapter

V. Student collaboration in group work

A. Collaboration recorded by virtual laboratory

An advantage of the virtual laboratory is its ability to track the students' participation. In a traditional educational laboratory, an individual student's participation in a group activity can only be evaluated through surveys. On the contrary, in the virtual laboratory discussed here, the evaluation can be accomplished by the computer automatically recording the students' activities.

In both the simple gear train and planet gear train laboratories, each student's assembly actions are recorded. Here, an "assembly action" is defined as any operation by which a student successfully connects two parts into a sub-assembly. For group work, the workload factor, which is defined as the ratio of the number of assembly actions of a member of a group to the number of assembly actions by the other group members, with the smaller number as the numerator, can be used for evaluating the students' group collaboration. The workload factor is 1 if two students balanced their work equally and it is 0 if one student did not do anything.

Figure 5 and Figure 6 show the distribution of the workload ratio for the simple gear train and planetary gear train laboratory exercises, respectively. In the figures, students who conducted the exercises individually were not counted. In the simple gear train laboratory exercise, the average workload ratio from 52 groups was 0.61, i.e. on average approximately one member completed 2/5 of all assembly activities while the other performed the remaining 3/5. In the planetary gear train laboratory exercise, the average workload ratio was 0.51 for all 46 groups, dropping from the previous 0.61. The reduction may have been due to 2 reasons:

1. Some students gained more experience from the first laboratory exercise than their group members. Therefore, they may have performed the laboratory exercise with less collaborative effort.

2. The planetary gear train laboratory exercise required less effort than the simple gear train laboratory exercise. Therefore, the students do not need to collaborate as in the simple gear train laboratory exercise.

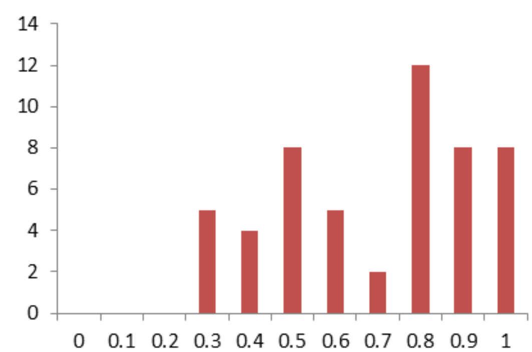

Figure 5: Workload ratio for simple gear train laboratory exercise

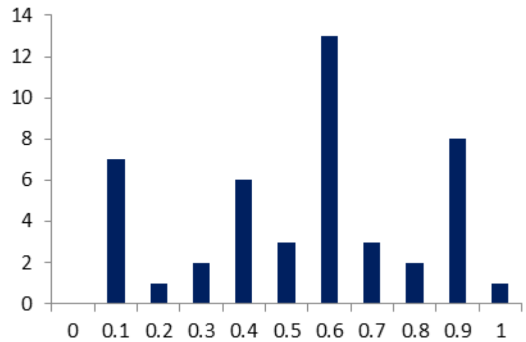

Figure 6: Workload ratio for planet gear train laboratory exercise

B. Collaboration self-reported by students

It is worth noting that the students were given surveys with 2 multiple choice questions about their collaboration immediately after each laboratory exercise:

1. What is your opinion of your group collaboration (5 – ideal, 3 – plain, 1 – bad)?

2. How do you evaluate your workload (5 – I did most of the work, 3 – we evenly distributed the work, 1 – my partner did most of the work)?

The results are listed in Table 4. Most of the groups were formed by self-affiliation. 6 groups in the simple gear train laboratory exercise and 4 groups in the planetary gear train laboratory exercise were arranged by the teaching staff. It can be seen from the table that, regardless of how the groups were formed, all students believed that they had an ideal partner. In addition, they all believed that they had evenly distributed the work, against the records collected by the virtual laboratory system. This result may have been caused by the students' personal relationships. Apparently, the students did not want to report their true opinion at the risk of harming their relationships.

Table 4: Students' self-reported collaboration results

Question number	1	2	3	4	5
1	0.00%	0.00%	0.00%	0.00%	100.00%
2	0.00%	0.00%	100.00%	0.00%	0.00%

VI. Student survey

In order to acquire the students' evaluations for the virtual laboratory exercises, a paper-based anonymous survey was administered after the students completed both laboratory exercises. The survey contained 3 multiple choice questions, which the students answered on a scale of 1-5, with 1 being the most negative and 5 being the most positive. The questions were:

1. What is your overall opinion on the virtual laboratory exercises?
2. How do you judge the difficulty of operating the laboratory system?
3. Do you feel you learned something?

The results from 108 responses are listed in Table 5. From the table, it can be seen that the average student response was 4.42 on question 1, 3.78 on question 2, and 4.05 on question 3. From the survey, it can be seen that most students favored the overall concept of adapting games to create educational laboratories. It can also be seen that the students' biggest difficulty in this form of laboratory was the operation. Many students felt challenged in learning how to operate the laboratory system. From a learning effectiveness perspective, the survey indicated that the students generally felt that the laboratory exercises helped them to better understand simple and planetary gear trains.

Table 5: Student survey results

Question number	1 – very negative	2 - negative	3 – neutral	4 - positive	5 – very positive
1	0.00%	0.93%	16.67%	22.22%	60.19%
2	0.00%	5.56%	34.26%	37.04%	23.15%
3	0.93%	3.70%	23.15%	34.26%	37.96%

VII. Conclusions

In this paper, evaluations of the learning effectiveness and the students' collaboration in virtual simple gear train and planetary gear train laboratory exercises were discussed. The virtual laboratory system was adapted from a popular video game. 110 Students who took the course "Machine Dynamics and Mechanisms" participated in the evaluation after they finished the gear chapter.

Both laboratory exercises involved a pre-laboratory test and a post-laboratory test, which included the same topics with different text, for evaluating the learning effectiveness. It was found that the students exhibited a better overall performance in the post-laboratory test than in the pre-laboratory test. The average scores in both post-laboratory tests were higher than those in the pre-laboratory tests; while the standard deviations for the post-laboratory tests were both lower. From the comparisons of the scores for the final exam questions on gears between the students who performed the virtual laboratory exercises in the spring semester of 2015 and the students who did not complete it in the fall semester of 2015, it can be observed that the students who completed the virtual laboratory exercises had higher average scores than those who did not.

From the students' collaboration data recorded by the virtual laboratory system, an overall imbalanced workload distribution among group members was found. In most of the groups, one student contributed more than the other. However, from their self-reporting, all students believed that they balanced their workload equally.

The student survey showed that the students generally accepted the concept of virtual laboratory exercises. 60.19% of the 108 students who responded to the survey gave very positive evaluations for the overall laboratory experience. From the operational perspective, the students felt that the laboratory exercises were hard to complete in the beginning. From the learning effectiveness perspective, 72.22% of the students positively evaluated the laboratory experience.

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