



Usability Evaluation of a Virtual Educational Laboratory Platform

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Abstract

Taking advantage of videogame technology, game engine-based virtual laboratories are able to offer promising immersive and collaborative learning experiences. Research indicates that such virtual laboratories can be viable alternative forms for laboratory learning activities with special advantages in distance education applications. Various researchers also evaluated whether students learned target knowledge via virtual laboratory exercises. However, several questions emerged during these evaluations: Can students complete this new form of laboratory exercises, which they have not encountered before, in an effective way? Can they collaborate in the virtual world like in the real?

This article tries to answer these questions by assessing the students' performances in two videogame-based virtual gear train laboratory exercises. Simple and planetary gear train scenarios were designed and implemented on the basis of Garry's Mod, a sand-box 3D game utilizing the Source game engine. 94 undergraduate students taking a course on machine dynamics and mechanisms were assessed right after completing the lecture and homework of the gear design chapter. Most of these students were randomly divided into laboratory groups of 2 while the remaining students conducted the laboratory experiments alone. In order to simulate a remote learning scenario, the students in each group were physically separated into two rooms so that they could not communicate directly with each other but could do so only by text-chatting within the virtual laboratory environment. A teaching assistant was present in each room to help the students.

In order to evaluate the usability of this game engine-based laboratory, a data set containing the students' videogame playing background and a game log, which tracks the students' activities, were collected and analyzed. The result shows that all students were able to complete the laboratories regardless of their prior videogame playing experience. Also, it was discovered that from the students' laboratory operation perspective, most students made mistakes before completing all tasks. From a collaboration perspective, most students in a group did not evenly distribute the tasks amongst them.

1. Introduction

“Laboratories are places where elegant theories meet messy everyday reality.” [1]. For engineering education, laboratories bridge the knowledge that is covered in textbooks and the skills that can only be acquired through solving real-world problems. With the emergence of online distance education, the traditional method of delivering educational laboratory exercises has been challenged. For distance engineering education, can a ‘messy reality’ that always hides the truth behind noise, errors and mistakes be delivered through the Internet? While there were doubts whether engineering educational experiments could be delivered remotely [2], there were also many solutions. Some of these solutions use computers to simulate the processes and results of experiments [3] [4]. Some other solutions, taking advantage of remote sensing and control technology, allow students to remotely connect to real experimental devices [5] [6]. There are also some solutions that combine virtual and remotely-controlled laboratories to create hybrid systems. [7]. Through these laboratories, students are enabled to conduct experiments following

predetermined guidelines and procedures. However, these laboratories lack flexibility as they only allow students to perform pre-designed activities.

Most remote laboratories are web-based: the students use Internet web-browsers to interact with the laboratory system. They can use the web-browsers to send commands and provide input data [8] [9]. They can also observe the experiment processes, which may either be simulated by 2D/3D computer graphics [10] [11] or captured by web camera at a remote location [12] [13]. Finally, the experimental results are presented to them, usually in the form of data lists or plots [14] [15]. It is easy for students to get started with these remote laboratories since the operation of these laboratory systems is similar to web-surfing and thus the students do not need training to complete the laboratory tasks. However, such web-based laboratories fall short of providing a 'messy reality'. On one hand, they do not provide the students with a feeling of immersion: experiments in the real world are not performed by clicking on hyperlinks or typing in text boxes. On the other hand, teamwork, which is a crucial aspect of traditional laboratories, is rarely integrated into such web-based laboratories.

Virtual reality technology can provide its users with a feeling of immersion and support team collaboration [16] [17]. Furthermore, state-of-the-art videogames engines can serve as an inexpensive workbench for authoring desktop virtual reality systems. Since 2007, the authors have worked on the development of a videogame-based laboratory platform [18]. The platform is based on Garry's Mod, a 3D first person shooting (FPS) game as the virtual environment authoring tool. During experiments, each student controls an avatar by mouse and keyboard. Through manipulating the avatar's movements, the students are able to mimic real-world experimental activities. In addition, multiple avatars controlled by different students can share the same virtual laboratory room. Thus, they can meet and collaborate. In addition, unlike most tools for authoring virtual environments, which require extensive hardware investment, Garry's Mod can run on personal computers, thus enhancing the versatility of the platform and reducing the development costs.

This virtual laboratory platform has an obvious disadvantage: its use is not as easy as browsing a website. Therefore, this paper tries to evaluate the usability of this platform from the perspective of human-computer interaction (HCI) and teamwork through two sample gear train laboratory exercises. With respect to the HCI, the students are challenged by their unfamiliarity with the operation of the laboratory system. In order to complete all experiment tasks, the students must operate a keyboard and mouse simultaneously with both hands, as they do in FPS games, because most basic operations on this platform are same as those in FPS games. As far as teamwork is concerned, the students may face difficulties in collaborating with their partners because it is actually their avatars that 'meet' and collaborate rather than the students themselves. It should be noted that a study of learning the effectiveness of this virtual laboratory platform is not the focus of the project described here but will be conducted and presented in the future. Because this platform is technically implemented to meet the needs of various mechanical engineering laboratory scenarios, rather than being limited to gear train laboratory exercises, the true learning effectiveness may largely depend on the specific laboratory designs implemented based on this platform. The evaluation of the usability of the platform addressed here can improve the further design of videogame-based laboratory systems for easier operations, which can help better motivating students as well as more efficiently rendering laboratory exercises implemented on this platform.

2. A videogame-based virtual laboratory platform

2.1. Designing virtual laboratories based on Garry's Mod

Garry's Mod is a modification (called 'mod' in the gaming community) of the 'Source' game engine, which is dedicated to FPS games and powers popular games such as 'Half-Life' and 'Counter-Strike'. Originally designed by team Garry for players to simulate their creative ideas (referred to as 'contraps' in the community) utilizing the physics simulation of the 'Source' engine, Garry's Mod allows game players to design their own games using Lua scripting. Lua scripting takes advantage of most functionalities provided by the game engine, while avoiding many restrictions imposed by the game engine when used to program directly by C++ language.

Besides Lua scripting, several tools were also utilized for designing the laboratory system described here. For instance, CAD software such as SOLIDWORKS and Autodesk 3ds Max for modeling mechanical parts, the 'Hammer' map editor of the 'Source' software development kit for building customized maps as well as the 'Valve' texture file editor for editing model textures. By integrating all these tools, a virtual laboratory can be implemented in an efficient way. The details of the design of the videogame-based laboratory system can be found elsewhere [19].

2.2. Operation of virtual laboratories

A student can perform various activities in the videogame-based laboratory. For instance, he/she can navigate through the virtual laboratory, manipulate mechanical part, try to assemble two mechanical parts and disassemble them if a mistake was made in the assembly. All these activities are controlled by mouse and keyboard.

For both simple and planetary gear train laboratories, the students' main task is assembling parts into a system. The students must select mechanical parts from a 'part shelf', which contains many parts provided by the laboratory designers, then use the left mouse button to pick up the part, move it by 'striking' navigation keys and perform the assembly as shown in Figure 1. In order to simplify the assembly process, the students only need to let two parts that they want to be connected touch each other. Then, the platform determines if these two parts have matching features and thus can be connected. If so, the platform imposes appropriate kinematic constraints on the parts to form a sub-assembly. Otherwise, the two parts remain separate.

Sometimes, when a wrong assembly was created, a student can select and pick up a 'disassembly tool' from the part shelf, and then he/she can move the tool to the wrong sub-assembly and touch the assembly with the tool. The platform then removes the constraints from the sub-assembly.



Figure 1: Assembly and disassembly operation in laboratories [20]

3. Evaluation procedure for laboratory system

3.1. Participants and form of evaluation

All students who recently took the course ‘ME358 Machine Dynamics and Mechanisms’ at the authors’ institution were mandated to participate in the videogame-based laboratory exercises. These students were all mechanical engineering majors. Most of them were in their junior year, while a few of them were in their senior year.

Before tackling the textbook chapter on gears, the students had completed the study of the fundamentals of machine, four-bar mechanisms and cam design.

The students could either perform the experiment alone or to collaborate with another student. All students used separate computers, no matter whether they worked alone or in a group. The students working in a group were not allowed to contact each other physically while performing the laboratory exercise.

3.2. Timeline of evaluation

The laboratory exercises were scheduled by appointment outside of the class time in the school’s computer laboratory. The timeline of the lectures and laboratory exercises is listed in Table 1.

Table 1: Timeline of evaluation

<i>Week</i>	<i>Activity</i>	<i>Note</i>
7	Taking videogame background survey	Students take a short survey via surveymonkey.com outside of class
8-9	Attending gear train lectures	Students learn fundamentals of gears, simple gear trains, compound gear trains and planetary gear trains
10-11	Attending simple gear train laboratory	Students perform simple gear train laboratory exercise in groups
12-13	Attending planetary gear train laboratory	Students perform planetary gear train laboratory exercise in groups
14	Taking evaluation survey	Students take a survey on their satisfaction with virtual laboratories

3.3. Tasks in simple gear train laboratory exercise

Both laboratory exercises follow a two-step procedure: tutorial reading and computerized experiment. Before a laboratory, a tutorial was distributed to the students. Through the tutorial, the tasks, the core knowledge and some tips were provided. Also included in the simple gear train tutorial were basic instructions on the operation of the laboratory system for students who were not familiar with FPS games.

There were four tasks in the laboratory as shown in Figure 2. The first task that the students had to complete was to assemble two shaft holders, a shaft and a gear of their choice. The second task was to select and assemble a meshing gear pair. In order to complete this task, the students had to review the relationship between pitch radius, module number and number of teeth, so that they could place the two gears at appropriate locations to let them mesh. The third task was to

insert an idler gear between the previous two meshing gears in order to create a three-gear simple gear train. Then, a three-question multiple-choice test about this gear train was administered by pop-up window. The students were allowed to answer the questions collaboratively via messaging inside the virtual laboratory. The last task was to let the students assemble a gear train with given performance requirements. The students had to carefully review these requirements, discuss the gears they may use and build the train together.

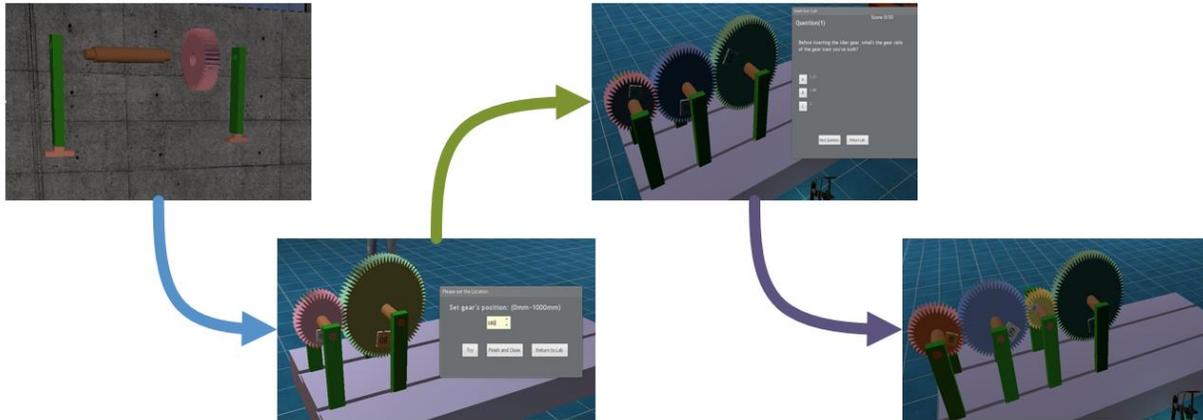


Figure 2: Process of simple gear train laboratory exercise

3.4. Tasks in planetary gear train laboratory

Like the simple gear train laboratory exercise, the planetary gear train laboratory also included a pre-laboratory test. Then, students began an experimental procedure involving the three tasks shown in Figure 3.

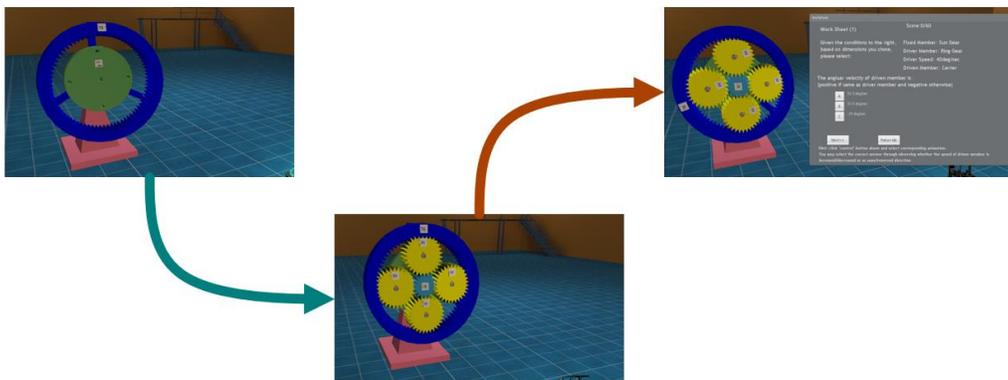


Figure 3: Tasks of planetary gear train laboratory exercise

As first task, the students were required to assemble the ring gear and the carrier. Then, they had to attach pins to the carrier and assemble the planet gears and a sun gear. Finally, they were required to answer three questions regarding the speed ratio of the gear train they had assembled, which they could answer by observing the kinematics simulation of the gear train.

4. Evaluation of laboratory exercises

4.1. Survey on videogame playing background

The evaluation of the laboratory exercises included a survey on the students' videogame playing background, a pre-laboratory test, the experiment itself, a student satisfaction survey, and a final exam. The videogame background survey was composed of 3 questions aiming to evaluate the students' gaming background including the frequency with which they played games, their exposure to various game genres and their familiarity with FPS games.

Form the survey, it was seen that only a few students had very minor prior videogame playing experience. In addition, there was an obvious difference between female and male students in playing games as most of the male students (74.36%) had played 20 minutes/week or more for some periods in their lives while most of the female students had played only a few games. The statistics is summarized in Table 2.

Table 2: Frequency of videogame playing of students

<i>Gender</i>	<i>> 2 hours/week</i>	<i>>20 min/week; <2 hour/week</i>	<i>A few times only</i>	<i>Never or Almost never</i>
Male	36	22	18	2
% Male	46.15%	28.21%	23.07%	2.56%
Female	1	2	8	5
% Female	6.25%	12.50%	50.00%	31.25%
% Total	39.36%	25.53%	27.66%	7.45%

Since the basic operations of the virtual laboratory system such as moving, turning, communication, etc., are the same as that in most FPS games, a question concerning the students' FPS game playing experience was also surveyed. The results are listed in Table 3. It turned out that 70 students (74.47%) new how to play FPS games. Since the laboratory exercises only require basic videogame playing skills, these students were classified as 'experienced' while the rest were considered 'inexperienced'.

Table 3 Students' previous exposure to FPS games

	<i>Played very well</i>	<i>Knew basic operations</i>	<i>Tried few times only</i>	<i>Never played</i>
	<i>(experienced)</i>		<i>(inexperienced)</i>	
Student	49	21	6	18
% Student	52.13%	22.34%	6.38%	19.14%

4.2. Assembly actions in gear laboratory exercises

In the laboratory exercises, the number of each student's assembly actions was recorded. Here, an 'assembly action' is defined as any operation in which a student successfully connected two

parts into a sub-assembly. For example, connecting a shaft and a holder in the simple gear train laboratory exercise is an assembly action.

The first concern to be analyzed was whether the videogame playing background of the students affected their participation in the experimental procedures. Table 4 lists the students' number of assembly actions taken and their respective game playing background. The table shows that although for both laboratory exercises, those students who had prior videogame playing experience on average assembled more parts, the difference in participation was not significant.

Table 4: Students' number of assembly action vs their videogame background statistics

	<i>Simple gear train laboratory</i>		<i>Planetary gear train laboratory</i>	
	<i>Average actions taken</i>	<i>Standard deviation</i>	<i>Average actions taken</i>	<i>Standard deviation</i>
Experienced game player	22.21	12.13	14.25	15.57
Inexperienced game player	20.52	11.57	12.61	13.93

The histograms comparing the distributions of number of assembly actions taken by experienced vs. inexperienced students are shown in Figure 4. The figure also indicates that those students who had little or no prior exposure FPS games could perform similarly well compared to those who are experienced in these games. Therefore, it can be concluded that the laboratory exercises had good potential for learning as the inexperienced players were also able to acquire the basic skills for operating the virtual laboratory system through the tutorial without major struggles.

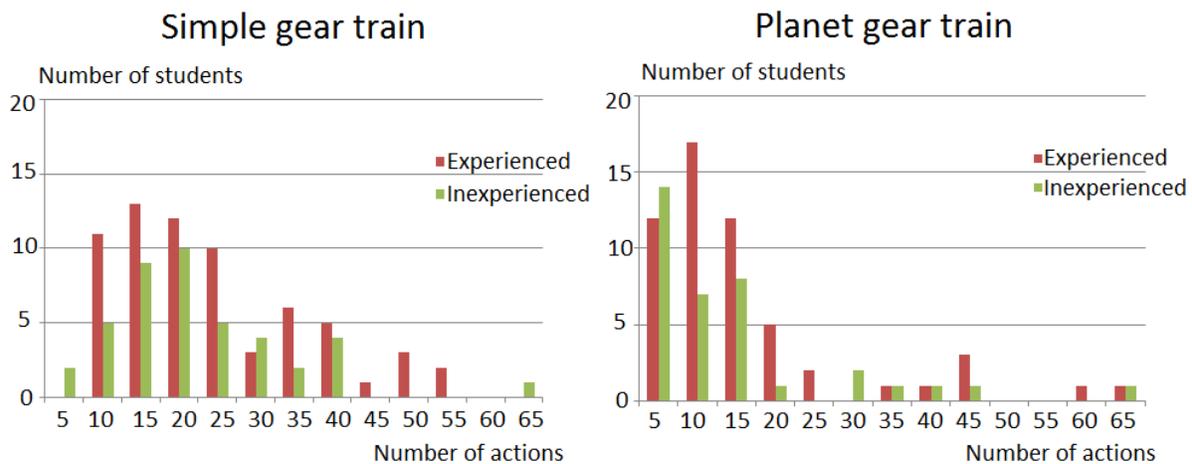


Figure 4: Comparison of number of actions as it relates to student background

4.3. Pre-laboratory tests score and final grades

In the simple gear train laboratory exercise, if no mistakes were made, each student group had to perform at least 16 assembly actions in order to complete all tasks. In the planetary gear train laboratory exercise, this number was 11. However, if the students made any mistakes such as

choosing the wrong gears or assembling them in an incorrect sequence, their number of actions would be larger, sometimes even significantly larger.

Using the number of extra assembly actions, how the students' learning background may affect the students' laboratory exercise performances besides their prior game playing experience can be assessed. It is possible that those students who exhibit a better course performance may also perform better in the laboratory exercises. Therefore, the students' pre-laboratory tests scores and final grades were gathered to examine whether there was any correlation between the students' lecture course and laboratory performances. In this paper, the grades were not used to assess the learning effectiveness of the laboratory exercises.

However, as was the case regarding the students' prior game playing experience, there was no obvious correlation between the students' learning in the lecture portion of the course and their performance in the laboratory. In the left part of Figure 5, the students' number of extra actions vs. their final grade (in percent). The graph in the right part of the figure shows the number of extra actions each student performed vs. their pre-test grade (in percent). Since the students had completed their study of the textbook chapter on gears before the laboratory exercises, a large portion of them earned the maximum of points in the test.

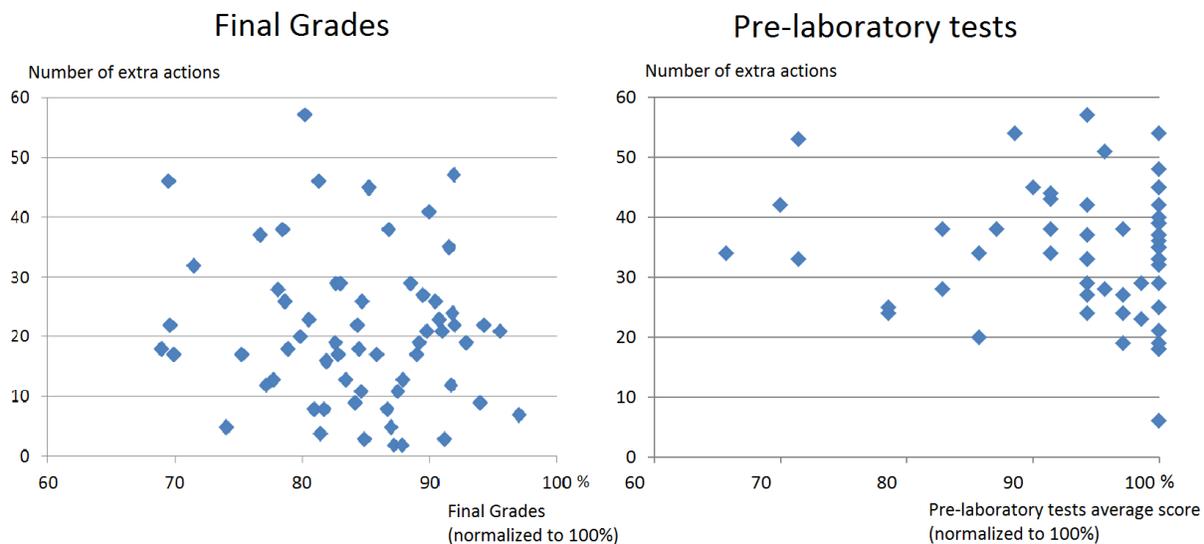


Figure 5: Comparison of number of actions vs. student learning

4.4. Students' group activities in virtual laboratory

By examining the number of extra assembly actions that each group had performed, the ease of use of the laboratory system could also be evaluated. Table 5 lists the overall average, standard deviation, maximum and minimum of the extra number of actions for all groups or individuals. From the table, it can be seen that on average each group took twice the minimum number of actions necessary, that is the students required several trial assemblies before completing all the tasks. It can also be noted that the average overall number of extra actions fell from simple gear train to planetary gear train.

Table 5: Overall number of extra actions for laboratories

<i>Laboratory</i>	<i>Average</i>	<i>Standard deviation</i>	<i>Maximum</i>	<i>Minimum</i>
Simple gear train	19.84	12.74	57	2
Planetary gear train	11.93	18.11	74	0

As indicated in Figure 6, the distributions the numbers of extra actions were quite different for the two laboratory exercises. For the simple gear train laboratory exercise, the distribution is relatively even for each horizontal-axis section. In the planetary gear train laboratory exercise, there were 26 groups or individuals (48.15%) that completed all tasks without any extra actions; while in the simple gear train laboratory exercise, there were none. From a conceptual knowledge perspective, planetary gear trains are much more difficult than simple gear trains. Therefore, it is possible that the reduction in the number of extra actions and the differences in their distributions were caused by the sequence of the two laboratory exercises. In the simple gear train laboratory exercise, the students may have been neither familiar with the operation of the laboratory system nor with the fundamental knowledge on gears. Therefore, a lot of trials were performed for the simple gear train assembly. The increase in the number of groups without any extra actions also indicates that the laboratory exercises lead students' self-tutoring. That is, most of the students could remember the operation of the laboratory system and thus were able to avoid making similar mistakes as in the previous experiment.

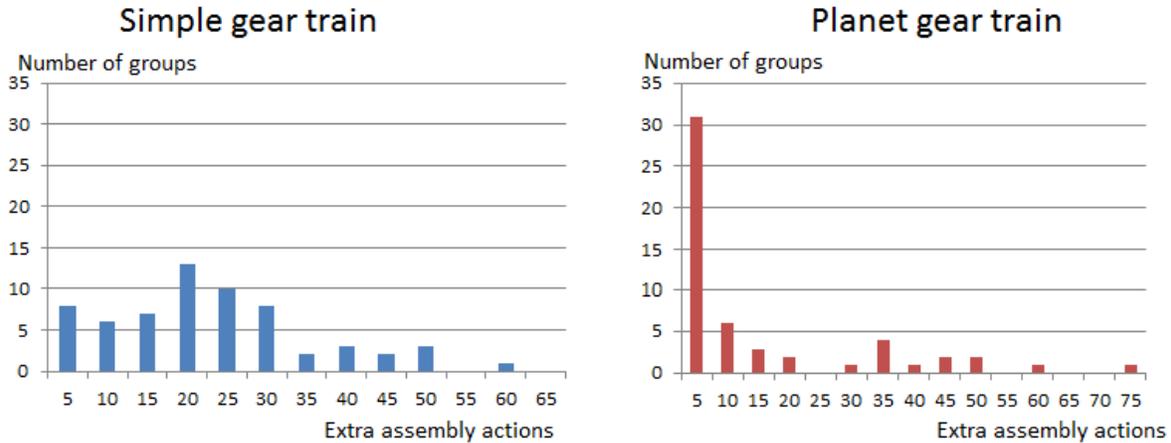


Figure 6: Histogram of number of groups by extra assembly actions

4.5. Collaboration within groups

In the laboratory exercises, some students were paired in groups of 2 while some other students completed all tasks alone. The paired students were prevented from talking to each other physically. Instead, they had to communicate via a text messaging system imbedded in the virtual laboratory system. In some groups, the group members talked frequently to coordinate their work. In some other groups, the members worked as if they were alone. The laboratory exercises required both students to participate. Therefore, for an ideally collaborating group, the

group members' workload should be balanced. Hence, the workload ratio was applied to evaluate whether the groups were communicating well and whether both members made an effort.

The workload ratio was simply defined as the ratio of the number of assembly actions of the two members, with the smaller number taken as the numerator. Hence, this ratio is always less than 1. The average ratio and standard deviation for each laboratory exercise is listed in Table 6 and the distribution of the ratio is shown in Figure 7. It can be seen that in general, the work was not balanced well between the group members. This could potentially be attributable to the fact that there were no group leaders specified for the groups and thus there was little or no coordination within the groups. Therefore, the organization of team working can be improved and more efficient communication methods such as voice chatting or video chatting may be deployed in future virtual laboratory exercises.

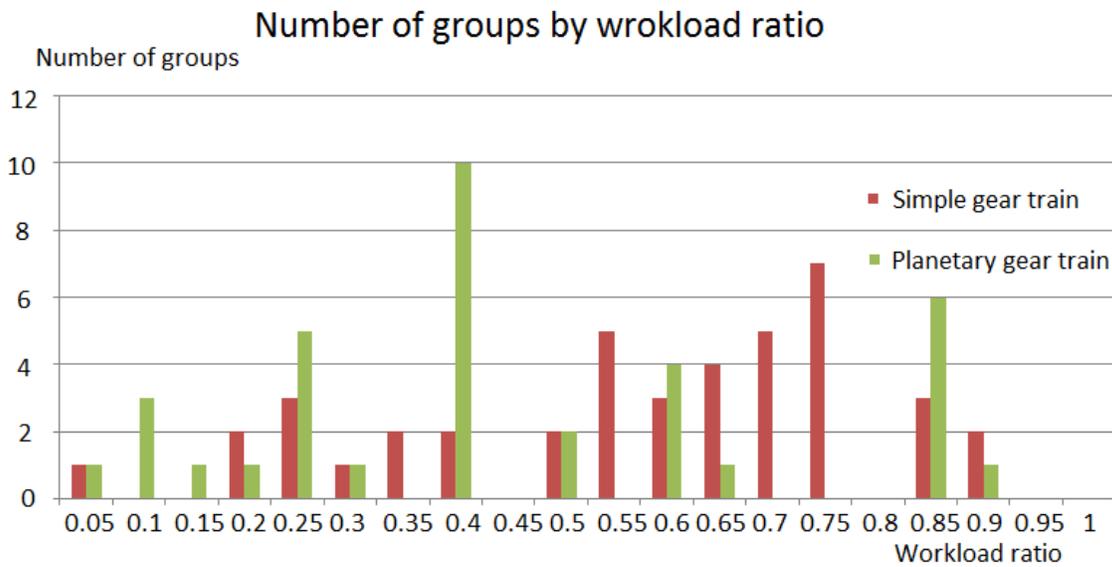


Figure 7: Distribution of workload ratio for both laboratory exercises

Table 6: Workload ratio statistics

<i>Simple gear train laboratory</i>		<i>Planetary gear train laboratory</i>	
Average ratio	Standard deviation	Average ratio	Standard deviation
0.56	0.21	0.42	0.25

4.6. Student evaluation survey

An anonymous survey on the students' opinions about the laboratory exercises was conducted. The survey included three questions regarding the students' overall laboratory experience, the operation of the laboratory system and the students' perceived learning effectiveness. The students answered on a scale of 1-5, with 1 being most negative and 5 being most positive. Table 7 lists the resulting evaluations from 87 students. From the table, it can be seen that the students generally gave positive evaluations regarding the videogame-based laboratory exercises.

From an operational perspective, most of the students assigned 4 points. This means that they thought the laboratory exercises could be conducted without spending major efforts on learning how to use the laboratory system by mouse and keyboard.

Table 7: Student evaluation survey result

<i>Question</i>	<i>Average score</i>	<i>5 point % (Positive)</i>	<i>4 point %</i>	<i>3 point %</i>	<i>2 point %</i>	<i>1 point % (Negative)</i>
Overall experience	3.90	36.78%	32.18%	19.54%	6.90%	4.60%
Operation easiness	3.74	20.69%	40.23%	31.03%	8.05%	0.00%

5. Conclusions

This paper presents a usability evaluation for a videogame-based virtual laboratory platform for mechanical engineering education. A simple gear train and a planetary gear train laboratory exercise were designed based on this platform. 94 students who took a recent course on machine dynamics and mechanisms were required to participate in these laboratory exercises as part of the course. An evaluation was conducted based on the students' prior videogame playing experience, their performance during the experiments and their subjective evaluation the virtual laboratory system.

From the evaluation results, it was observed that students were able to complete all experimental tasks for both laboratory exercises, regardless of their prior videogame playing experience. From the number of assembly actions performed by each student, it was also discovered that the laboratory exercises have good learning potential as the inexperienced videogame players were able to perform almost the same number of assembly actions as the experienced players in a limited time period. It was also found that the students' learning background did not exhibit a significant correlation with their laboratory performance. From comparisons of the students' performance between the two laboratory exercises, it could be seen that the laboratory exercises also lend themselves to memorization as most of the students made fewer mistakes in the second laboratory exercise despite it being more difficult in principle. Finally, the students' evaluation surveys indicate that most of the students were quite satisfied with the virtual laboratory exercises in general, the ease of operating the laboratory system and their perceived learning effectiveness. In a future study, the learning effectiveness assessment of the laboratory exercises designed using this game-based virtual laboratory platform will be conducted.

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