AC 2010-161: DESIGN IMPROVEMENT AND ANALYSIS ON 3D HAPTIC-AUGMENTED LEARNING TOOLS FOR DYNAMICS COURSE

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Design Improvement and Analysis on 3D Haptic-augmented Learning Tools for Dynamics Course

Abstract

The paper presents the recent improvement and analysis of 3D haptic-augmented learning tools for Dynamics course, which is a fundamental course offered in most engineering disciplines. Dynamics is considered to be one of the most difficult and non-intuitive courses that engineering students encounter during their undergraduate study. Haptics, the research and application on the sense of touch and force feedback, provides a novel human computer interface for students to interact with virtual dynamics world to potentially gain a better understanding of the dynamics concepts. Under this assumption, this research started with the identification of key dynamics concepts from engineering teaching experience and converted these concepts into interesting interactive animation with both graphics and haptics learning channels. The developed learning tools have been tested with 99 undergraduate engineering students in Spring 2008, Summer 2008 and Spring 2009 semesters. The positive effect of the novel learning tools is confirmed with the statistical analysis of the experimental result. The analysis result also provides great input to future improvement and dissemination of the novel teaching methods on dynamics concepts.

1. Introduction

Dynamics is an important engineering course for three reasons. First, it is essential to have a strong grasp of the concepts covered in the course when pursuing a degree in engineering. Second, it is a required course for many engineering departments and is the first engineering course that covers both difficult and abstract concepts. Third, for many capable students this course can become a roadblock to a career in engineering[1].

Computer-mediated instructional technologies, typically in Virtual Environments, hold great promise for use in educational settings in that they can increase students' access to knowledge and act as vehicles that may promote learning[2]. Traditional Virtual Environments only provides visual and/or audio feedback. Recent advances in Virtual Reality and robotics enable the human tactual system to be stimulated in a controlled manner through 3-dimensional (3D) force feedback devices, a.k.a. haptic interfaces[3]. Virtual Reality / Augmented Reality (AR/VR) technologies have been used widely in the educational settings[4]. Graphics and audio contents are extensively used in these VR/AR educational applications, while the inclusion of a haptic interface is still limited. Williams (2003) utilized a 2D haptic interface for teaching Physics, Statics and Dynamics in Ohio University[5]. Researchers at Hiroshima City University (Japan) have demonstrated their initial attempts in introducing 3D haptic interface into Dynamics Learning System[6].

In this study, 3D haptic-augmented learning tools have been created and used to complement the course materials in Dynamics course. We have presented the first part of our research in ASEE 2009 conference[7]. In this paper, we are going to report our design improvement and new data analysis based on the new experiments on the renovated material in Spring 2009 semester. The rest of the paper is organized as follows. Section 2 describes the development process of the 3D haptic-augmented learning tools. Section 3 narrates the experimental process. Section 4 presents the experimental result analysis and discussion. The paper is concluded in Section 5.

2. Improvement of the 3D Haptic-augmented Learning Tools for Dynamics

Previous studies in Engineering Education have explored students' misconceptions in Dynamics. The Delphi study was the primary source used by the researchers to gather information from faculties about the difficulty and importance of Dynamics concepts[8]. Delphi studies are conducted with Delphi groups, which consist of members who are not always in contact with each other, but have special domain specific knowledge to share. It makes use of mail or computer systems to send a series of questionnaires to a pre-selected group of experts to analyze a specific problem. A study at the Colorado School of Mines conducted used Delphi study to identify difficult to understand, yet important, concepts of engineering[9]. If the misconceptions or alternative conceptions dominate, they make learning complex theories in the Dynamics course very difficult. For example, prior research shows that many students found friction a difficult concept, as they could not see friction force with their eyes, but could realize its existence through the resistance to motion[9]. Another study at Pennsylvania State University was conducted with twenty-five dynamics faculty members with good experience from community colleges to research universities[10]. The conclusion is that more efficient methods are necessary to teach these difficult concepts. This claim was tested by Gary L. Gray and associates (2003) at Pennsylvania State University when they validated the effectiveness of new teaching methodologies and curricula innovations. They conducted the DCI (Dynamics Concepts Inventory) test to over 450 students at a large public university and at a small private university[10].

Based on the previous research results on 'Dynamics Concepts Inventory'[6] and the authors' teaching experience, the following exemplary Dynamics problems have been identified as presented in our paper in ASEE 2009[7] (Table 1).

Table 1 Concepts and Exemplary Problems

NO	CONCEPT	PROBLEM
1	Sliding and Rolling Motion	Motion of a block and a ball on a plane
2	Impulse and Impact	An impact between two balls
3	Centripetal and Centrifugal Forces	Particle waltz
4	Coriolis Acceleration and Force	A slider on a rotating arm
5	Kinetics of Rigid Bodies	A piston-crank mechanism of an internal combustion engine

Corresponding to the key concepts listed in the Table 1, software tools have been developed as the new learning materials which were tested with students in Spring 2008 and Summer 2008 semesters. Based on the student and faculty feedback on the software, we improved the software design and the learning materials in Fall 2008 and a set of new experiments were conducted in Spring 2009 semester. In the newly designed software, Open Dynamics Engine (ODE) was used as the dynamics engine to support the computation in our graphics and haptics applications. Open Dynamics Engine (ODE) is an open source, high performance library for simulating articulated rigid body dynamics[11]. Irrlicht3D is adopted as the graphics engine. It is a popular open source graphics engine based on OpenGL. OpenHaptics SDK from SensAble Technologies Inc. is adopted as the haptics engine[3]. The haptic devices used in the experiments are five sets of Phantom Omni. The software user interface was greatly improved to be more user-friendly and more professional. The students can quickly learn how to use the self-explanatory software. At the beginning, the user will be presented with a screen carrying very simple instruction as shown in Figure 1. Once the student click the OK button to dismiss the help message, he or she can proceed to work on the five conceptual demos by clicking the five tabs in the 'Change Settings' dialog box as shown on the upper right corner of the screen. In the 'Change Settings' dialog, the user can feel free to change the parameters, see the result visually and feel the force with haptic interface if applicable. Before they start with each concept, they are asked to listen to a short audio (as part of the software) describing each problem.

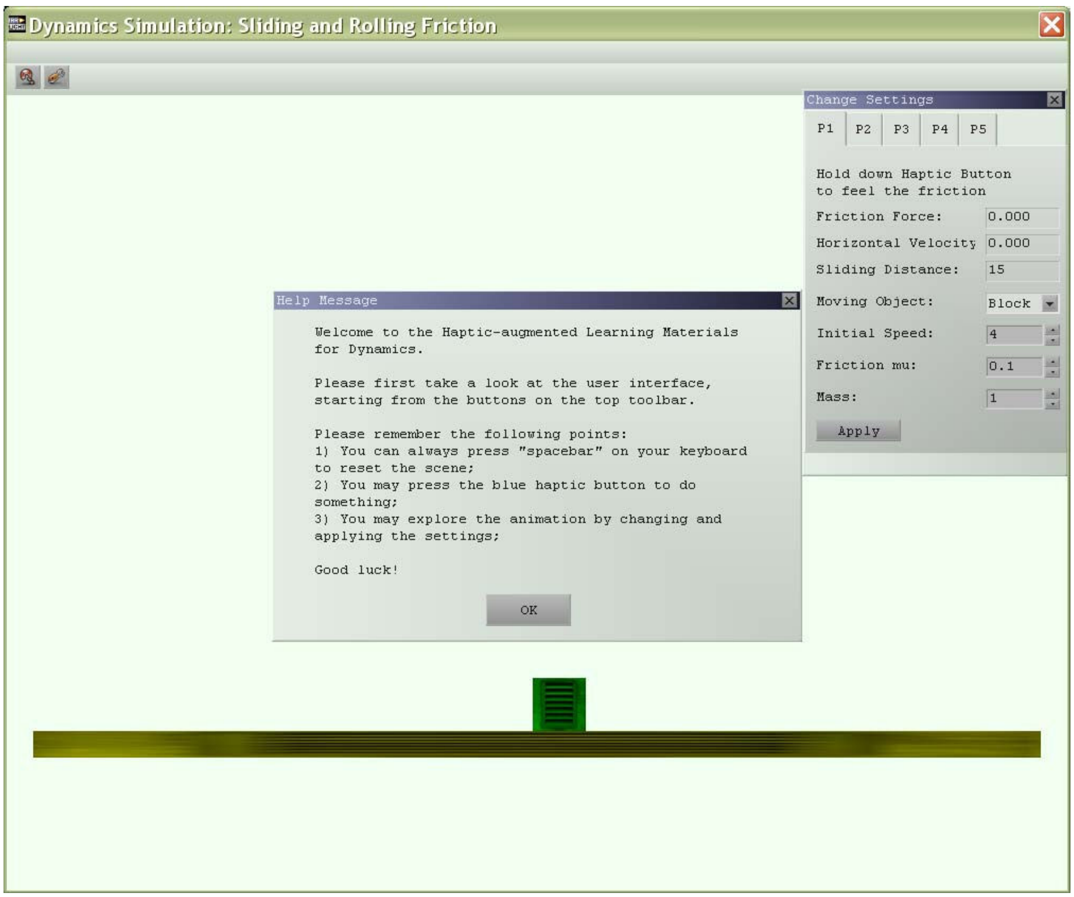


Figure 1 Introductory Screen for the Haptic-augmented Dynamics Learning Software

The five demos are described as follows. Along with the software, a student learning guide is furnished to the student who will follow the guide step by step to complete the learning. In the guide, the students will be asked to change some parameters, watch the effect and feel the force is applicable. The students then will be told to try different parameters as they wish. At the end of each demo, the students will be asked a few review questions to further enhance their learning.

***Concept 1*:** Sliding and Rolling Motion

There are two cases. The two cases look similar but work differently for the block and the ball. One can feel the friction force with a haptic device.

1) A block moving with an initial speed on the surface from left to right: because of the friction on the surface, the block gradually slows down, until it comes to a full stop. The block slides on the surface all the time.

2) A ball (sphere) with an initial speed on the surface from left to right: because of the friction on the surface, the kinetic energy of linear motion is gradually converted into the kinetic energy of the rotational motion. This means that at the beginning of the motion, the ball is both sliding and rolling. At a certain moment, the ball is no longer sliding as the contact point between the ball and the surface has a zero velocity, which means there is no friction at the contact point. Thus the ball will keep moving at a constant speed. And this motion is pure rolling, without sliding.

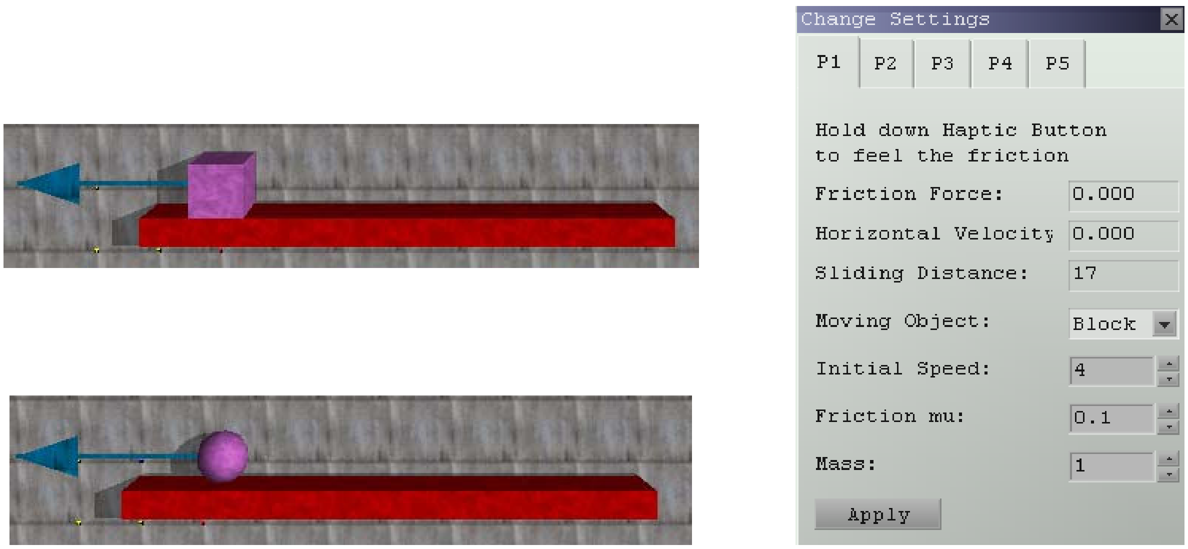
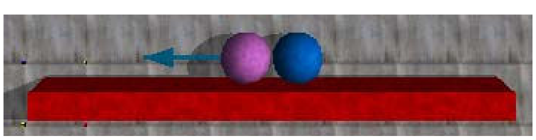


Figure 2 Parameters for Rolling and Sliding Objects on a Flat Plane

***Concept 2*:** Impulse and Impact
Two (billiard) balls collide with each other: direct impact or oblique impact. The initial velocity of the balls can be changed through the user interface. By pressing and holding the blue button of the haptic probe, one can drag one ball and try to hit the other and feel the collision force.



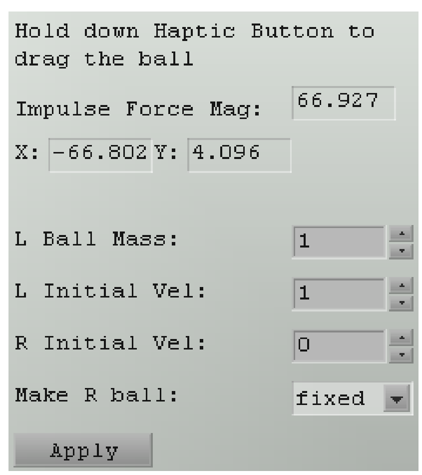
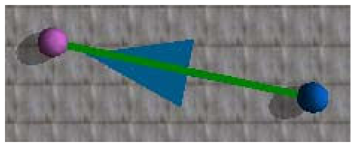


Figure 3 Two Balls in Collision and the Parameters

***Concept 3*:** Centrifugal and centripetal forces

This demo shows particle-waltz example. Two particles are used to represent two persons. They are dancing like in a waltz. One particle is leading the other. The other particle follows the motion of the first particle, as if the two are connected with a rubber band. The force arrow shows the magnitude and the direction of the centripetal force. One can feel the centripetal force when dragging the ball with a haptic device.



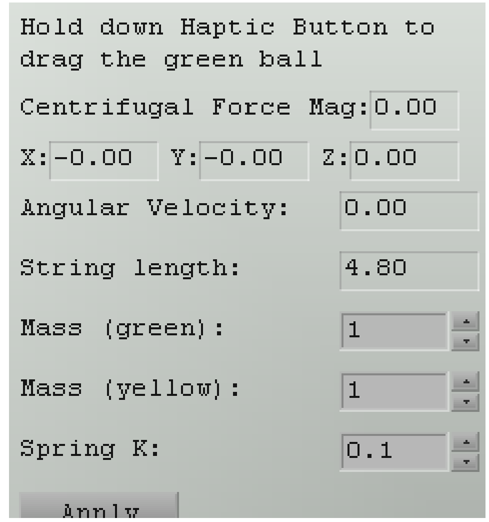
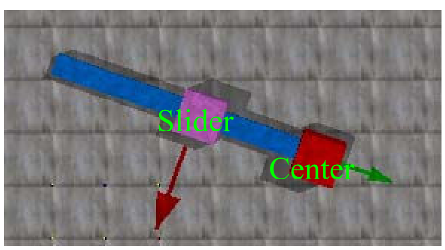


Figure 5 Particle Waltz Example

***Concept 4*: Coriolis acceleration and force**

This demo shows Coriolis acceleration and its corresponding Coriolis force. It shows a rotating bar, which rotates at a constant speed. On the rotating bar, a slider block is moving at sine wave motion (autonomously). This example demonstrates the centrifugal force and the Coriolis force at the same time. With a haptic device, one can feel the Coriolis force when following the motion of the slider.



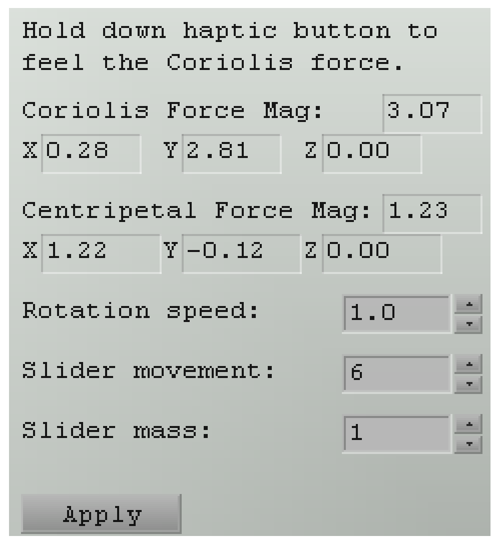
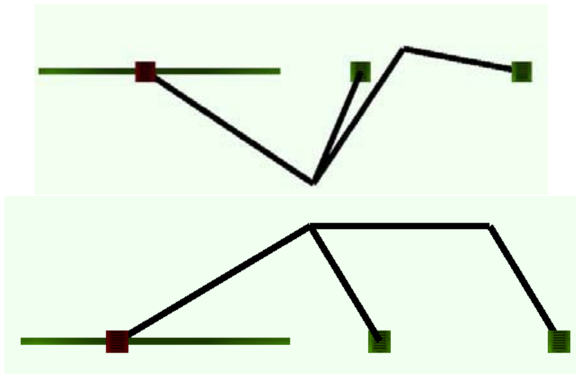
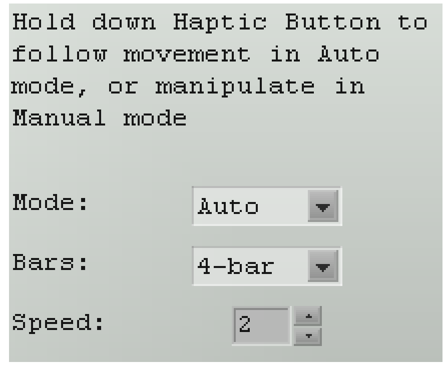


Figure 6 Coriolis Force and Acceleration Example

***Concept 5*: Kinetics of Rigid Body**

This demo shows the slider-crank mechanism of an internal combustion engine. Generally speaking, there are three types of planar motion: 1) linear translation; 2) rotation; 3) combined translation and rotation in a plane. In a slider-crank mechanism, the slider is moving at linear translational motion; one link is at rotational motion; the other link is at combined translational and rotational motion. In this case, the slider is actually the piston of a car engine and it drives the crank and wheel. One can switch between a 4-bar and a 6-bar mechanism. One can drag the slider to move the mechanism with a haptic device.





3. Student Experiments Procedure

The innovative course materials have been used in teaching 58 students in the Spring 2008 and Summer 2008 semesters. The revised materials have been used for 41 students in the Spring 2009 semester. A pre-/posttest experiment with the undergraduate engineering students was conducted. We spent one lecture session on informing the students the lab contents and conducting the pre-assessment and data collection. At pre-test, all participants were presented with a battery of spatial reasoning and problem-solving ability tests. After that, we scheduled the lab session with for the students. The students were divided into a haptics training group and a control group to be taught with haptic interface also but without force feedback. Each participant was assigned to one of two groups: a) *Graphics group*: Participates in the pre- and post-test, but is taught *Dynamics* with haptic interface but without force feedback, i.e., one can interact with haptic interface but cannot feel the interaction force even if it exists; b) *Haptics group*: Participates in the pre- and post-test, but is taught *Dynamics* concepts combined with haptic-augmented animation. The students were grouped so that each group of students had similar starting knowledge based on the pre-test. The effectiveness of the exemplary learning materials and tools was measured through analysis of survey and interview data (indirect measure) and post-test (direct measure).

Altogether 41 students took the pre-assessment. There were 12.1% female students. The minority was 34.1% of the whole batch. Altogether the percentage of the students from the underrepresented group was 43.9%. Due to the scheduling conflict, only 40 students were able to complete the lab sessions. These 40 students were split into two groups: 20 students in the graphics group and 20 students in the haptics group. The students were given the initial instruction for a few minutes. They were trained on how to use a haptic interface until they felt comfortable in using the device. They did not know which group they were in until they started to play with the haptic interface. During the experiments, the students followed the instruction manuals to complete the learning. They were asked to listen to the audio instruction first and then followed the manual step by step to interact with the animation with the haptic interface, either with or without force feedback. When the one hour lab finished, they were asked to take the paper test again (post-test) and completed the interview and survey with the instructor. During the one hour learning lab, there was no interaction between the instructor and the students. Therefore, the variation factor of differences in instructors did not affect the experiment result. The 40 students who completed all the study were paid for their participation.

4. Experiment Result Analysis

From the student experiments, many results are collected from the assessment materials. The following analyses include the cognitive domain and the affective domain of students' learning. The data analysis was conducted with MiniTab® statistics software.

The purpose of analyses on the *cognitive* domain is to find out whether students have learned from the lab, and whether haptics impacts their learning. The data used are pre- and post-test assessment scores on all the 5 problems / concepts as discussed in Section 2. Both groups of students entered the study with similar knowledge on all five cognitive items, as evidenced by lack of significant differences in their pre-test scores on all the five problems.

In order to assess if 'learning occurred' during the lab study in each group, paired t-tests (two-tailed, $\alpha = 0.05$) were used to determine whether the means of the post-tests were significantly different than those of the pre-tests on each problem in two treatment groups, i.e., haptics group and graphics group. It was found out that here were significant differences in the students' pre- and post-test scores on all problems in both groups.

The comparison conducted between the Graphics group and the Haptics group provides insight on whether haptics information provides additional help in achieving learning goals. First, we compared the learning improvement results between the two groups to see whether the Haptics Group achieved better learning improvement than the Graphics Group. To test for significant differences across two groups, gain scores on each problem were compared using two-sample independent t-tests (two-tailed, alpha = 0.05). The gain score is obtained by subtracting the pre-test scores from the post-test scores in each group[12]. The t-test tells us that the gain scores of the Haptics Group are better than those of the Graphics Group. This confirms that the haptic force feedback helps student retention of the concepts.

The purpose of analyses on the *affective* domain is to find out the attitudinal changes of the students through the new learning materials. The post-instruction Assessment of Instructional Module (AIM) questionnaire was analyzed for differences in students' attitudes toward the instructional program. This instrument contained mostly Likert-scale (from 1-'strongly disagree' to 7-'strongly agree') items that asked the students to report their attitudes towards and interest level in the instructional program. Some questions are intentionally reversed in meaning so that students will have to read the questions carefully before they make the selection. There are twenty questions with Likert-scale (from 1-'strongly disagree' to 7-'strongly agree') and three additional questions on a scale of 1 to 10. Some of the questions are related to the usability of the software and some are related to the attitudinal changes of the students. We report the results to the attitudinal changes questions here. The questions are:

- Q1: I am more interested in 'Dynamics' course after using the program.
- Q2: I believe that I have learned a lot more about these dynamics concepts by participating in this activity.
- Q3: I hope to use similar programs to help me learn other Engineering courses if applicable.
- Q4: I think using the haptic device is useful in helping me learn these Dynamics concepts.
- Q5: I think I can learn more by using the haptic device combined with animation, compared

to if I only can see the animation without force feedback.

- Q6: On a scale of 1-10, with 1 meaning not at all interesting and a 10 meaning extremely interesting, how would you rate your enthusiasm in participating in this lab BEFORE attending the lab?
- Q7: On a scale of 1-10, with 1 meaning not at all interesting and a 10 meaning extremely interesting, how would you rate your enthusiasm in participating in this lab AFTER attending the lab?

Q1~Q5 are with Likert Scale from 1 to 7 while Q6 and Q7 are on a scale from 1 to 10. Since the data collected for these *Interest* items are ordinal, pair-t test is not suitable. Hence, a nonparametric test, the Mann-Whitney test (*a.k.a.* Wilcoxon Rank-Sum Test) is adopted for analysis, using MiniTab. The significant value α is selected as 0.05. According to the P-Value, there are no significant differences in Q2 ~ Q5, but there are significant differences in Q1. Checking with the actual questions, we can conclude that students in both groups are positive about the instructional materials, while students in the haptics group are more positive towards the Dynamics course after the instruction. The difference between Q6 and Q7 tells us the attitude of students towards the lab instruction. A method similar to gain score method was used to take the difference after the lab *vs*. before the lab. It was found out while both groups like the lab material, the haptics group is more interested after the lab instruction. In the review after the lab instruction, students in the graphics group expressed their desire to use haptic interface with force feedback and were a bit disappointed when they found out they were in the graphics group. Nevertheless, both groups are positive about the learning materials.

5. Conclusions and Future Work

The development and analysis of the new 3D haptic-augmented learning tools provide us insights into the possible impact of the haptics in the engineering education. The assessment result shows that the innovative learning tools: 1) allow the students to interact with virtual objects with force feedback and better understand the abstract concepts by investigating the dynamics responses; 2) stimulate the students' learning interests in understanding the fundamental physics theories.

As the future work, we will look into expanding this haptic-augmented learning into other engineering courses to improve student learning. Additionally, more judicious design of experiments and data analyses are necessary to reveal the potential of haptics in an Engineering classroom.

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