AC 2010-1731: MULTIMODAL LEARNING INTERFACES: ASSESSING THE EFFECTIVENESS OF HAPTIC AND VISUAL INTERFACES ON STUDENT LEARNING OF STATICS

Sarah Bouamor, University of Oklahoma

Chen Ling, University of Oklahoma

Binil Starly, University of Oklahoma

Randa Shehab, University of Oklahoma

Multimodal learning interfaces: Assessing the effectiveness of haptic and visual interfaces on student learning of statics

Abstract

Haptic technology is becoming more widely used as an educational tool. Providing force feedback to the students may improve their interest and understanding of the engineering subjects. In this study, we developed a multimodal user interface based on haptic technology and visualization to teach engineering statics concepts. The objective was to test the effectiveness of multimodal experience of haptics and visualization in teaching the statics concepts, as compared to the traditional teaching method. Twenty participants learned statics concepts illustrated with a beam problem in the classroom. They were then randomly divided into two groups. The first group carried out tasks in a multimodal lab, and took an exam. The second group took a pre-lab exam, performed tasks in the multimodal lab, and then took a post-lab exam. Both groups filled out a survey afterwards. Exam performances were compared between those who took the pre-lab exams with those who took the post-lab exams. The participants who performed tasks with the lab solved more of the difficult statics problems in the exam correctly, as compared to those who did not perform tasks with the lab. The results of survey evaluations of the multimodal lab showed an improvement in the understanding of the statics concepts and a real interest for the subject taught with the use of the multimodal experience. The results showed that educational haptics and visualization can bring a fundamental change to the way the engineering concepts are taught and learned.

Introduction

It is challenging in education to make the learning process appealing for students and to help students build the connection between theory and physical reality. Haptics technology is becoming more widely used in the educational field to increase students' interest in learning and enhance student understanding of course materials. Haptics refers to sensing and manipulating through touch . The development of haptic technology allows human to interact with the virtual environment by feeling, touching, and manipulating objects through haptic devices. The haptic device is able to measure the positions and contact forces of the user's hand, calculate the force and torque that the user should have encountered in the virtual environment in real-time, and display them back to the user through actuators, leading to a haptic perception of the virtual objects.

Researchers have explored the application of haptics in various educational fields. In the medical field, haptic senses were incorporated in surgical simulators to enable medical trainees to see, touch, and manipulate realistic models of biological tissues and organs[1]. In a recent study [2], the haptic technology was used to teach middle schools students about virus structure. The students showed significant gains in their understanding of viruses. They also considered the learning experience engaging and developed more positive attitudes about science. The use of haptic technology was also used to help visually-impaired students to learn. Jones, Minogue, et al.[3] examined how tactile and kinesthetic feedback influenced the learning about cell morphology for visually impaired students. The students explored the cell structure with a haptic point probe that allowed them to feel the cell. They showed significant gains in their abilities to understand cell morphology, and considered the technology highly interesting.

In the field of engineering education, the educational benefit of haptic technology has also been explored. Grow, Lawton, and Okamura[4] introduced a haptic paddle, originally designed by a research group at Stanford University[5], as a dynamic model in a lab of a dynamics system course. The undergraduate students were asked to assemble, model, identify, calibrate, and program the device. To quantify the pedagogical efficacy of haptics, a quiz was administered before and after the hands-on exercises. The results showed significant improvement of students' acquisition of knowledge and their understanding of the material. On the average, the scores after the lab were 10% higher than those before the lab. Besides, the researchers observed that the concepts taught in the lectures were fully assimilated for the first time by many students after the haptics lab sessions. Another study that incorporates haptic sense to teaching engineering concepts was by He [6]. The researcher explored the use of haptic devices to augment the teaching and learning of undergraduate engineering courses including Physics, Dynamics and Statics. A low-cost, programmable haptic device with two degrees of freedom, Microsoft Sidewinder Force Feedback 2, was used. Responses to a survey at the end of the experiments indicated that the undergraduates generally felt the haptic software supported their learning of concepts such as curves and surfaces, gravitational forces between planets, magnetic fields, and dynamic systems.

So, what is the added value of a haptic experience? It is difficult for the students to maintain attention and motivation in a passive learning context. Instead, engaging the student's haptic sense affords an active learning context. With the multimodal interaction that incorporates both the visual and haptic senses, students can become fully immersed in the learning process of sense-making. In the studies mentioned earlier, the haptic experience added to students' understanding, and all students thought of the haptic experience through the virtual environment as exciting and engaging. If the haptic experience is closely integrated with visual presentations, it could illustrate difficult problems in a powerful way, and therefore assist the student's knowledge assimilation process.

The objective of the current study is to explore the effectiveness of incorporating the multimodal interactions including haptics and visualization into the learning process of the statics concepts. Students' understanding and assimilation of concepts gained during the traditional classroom teaching were compared to those gained during lecture supplemented with a multimodal lab. Because most engineering students' learning styles are active, sensing, visual, and sequential[7], the inclusion of a multimodal lab should provide an active learning environment, and therefore fits the majority of engineering students' learning styles better. We hypothesized that the students would solve difficult problems that require intergradations of knowledge more effectively with the help of multimodal labs, as compared to merely with the traditional classroom lectures.

METHOD

Participants

Twenty participants with an average age of 22.2 volunteered for this study. They were college students in the University of Oklahoma. They had different educational backgrounds, but most of them were students from engineering majors. To qualify for this study, all participants had to have had freshman level calculus and physics, but no prior experience with statics concepts.

The Multimodal lab

A multimodal learning interface "Cantilever Model" was developed within the Visual C++ environment with a visualization interface and a haptic device PHANTOM Desktop. The haptic device has six degrees of freedom which allow users to feel high fidelity haptic force-feedback (see Figure 1). The interface is designed around the concept of beam problem, which is one of the statics problems that are simple yet powerful to showcase important statics concepts.

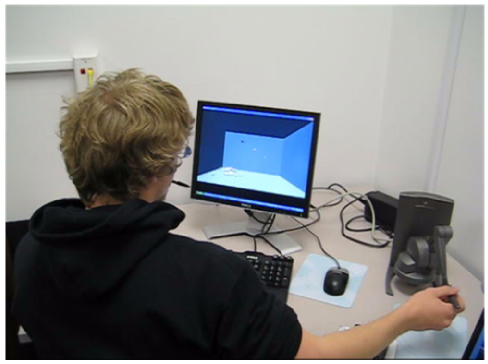

Figure 1. A Student Interacts with a PHANTOM Desktop Haptic Device in The Lab

The multimodal lab was based on a 2D graphic user interface which presented the beam problem (see Figure 2). The interface was connected to the PHANTOM haptic device, which allowed the students to interact with the interface haptically while solving the statics problems. In the beam problem, a simply supported beam was pinned at one end and roller-supported at the other. It was intended to resist concentrated vertical load. The beam was sectioned into units with five endpoints. In the lab, participants interacted with multimodal learning interface by pointing the cursor at any endpoint on the beam, pressing the stylus button on the PHANTOM haptic device to engage the beam, and pulling in certain directions. As a result, they felt the magnitude of the applied load haptically, and observed the effect of their action on the shape changes in the shear force diagram and the bending moment diagrams. The force magnitudes and shear-bending moment diagrams were constantly updated as the user applied different amount of force. In the lab, the users were asked to change three parameters of the beam problem: the application point of the force, the length of the beam, and the location of the roller support, as they applied different amount of forces on the beam and experienced the differences.

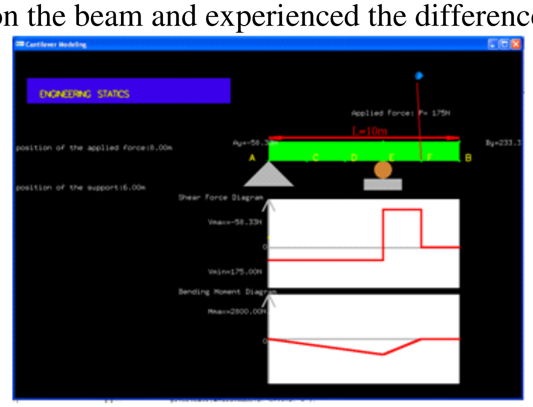

Figure 2. A Haptic Interface of a Beam Problem
with Shear Force and Bending Moment Diagrams

An exam was designed around the beam problem by a subject matter expert, who knew which material was difficult for the students to understand based on his teaching experience. There is a common lack of understanding of the importance and purpose of the shear force diagram and bending moment diagrams among engineering students. Although students know how to solve the problem and derive the diagram, many lack the understanding of what the graph really means and how it becomes useful in designing beams for structures. Moreover, it is common for students to learn how the role played by the parameters within the equilibrium equations without fully understanding the role that each parameter played on the end effect. To evaluate the students' depth of learning, the exam was designed to contain 10 questions, five of which were classified as difficult and five as easy by the subject matter expert. The difficult questions required deeper understanding and integration of the knowledge about the shear force and bending moment diagram, and the easy questions required simple acquisition of basic concepts.

Procedure

The experiment started with a traditional statics lecture in a classroom on the beam problem. After the lecture, the participants were assigned to one of two groups randomly. The procedures that each group went through are described in Figure 3. Group 1 completed a series of tasks in the 15-minute multimodal lab. Then they worked on an exam. Group 2 worked on the exam immediately after the lecture. Then, they performed tasks in the multimodal lab, and worked on the same exam again afterwards. Participants in Group 2 were not aware that they were to be tested again with the same exam. At the end of the experiment, all participants filled out a survey to evaluate their experiences with the multimodal lab. Figure 3 illustrates the procedure of the experiment.

The multimodal lab started with a tutorial of the PHANTOM Desktop haptic device. Because of the device's intuitive design, the students grasped the idea and method to use the haptic device instantaneously. The performances on the exams in terms of the numbers of difficult and easy questions correctly solved were compared. Two sets of comparisons were performed. In the first comparison (as indicated as comparison 1 in Figure 3), the performance between the post-lab exam for Group 1 participants and pre-lab exam for Group 2 participants were compared. The hypothesis was that inclusion of the lab in addition to the traditional lecture would enhance the exam performance in terms of number of difficult problems that the students were able to solve.

In the second comparison (indicated as comparison 2 in Figure 3), the performances in the pre-lab and post-lab exams were compared for participants in Group 2. The hypothesis was that with the multimodal lab, the participants would be able to solve more of the difficult problems correctly as compared to before the lab.

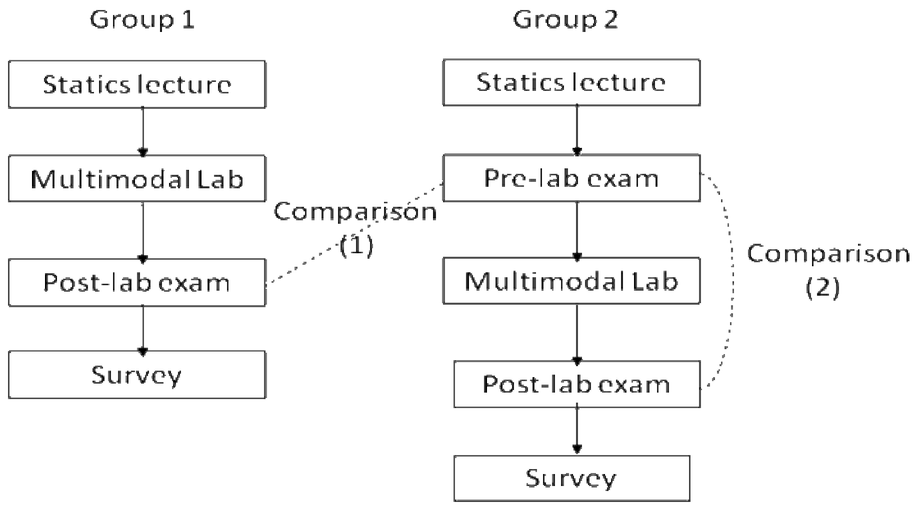

Figure 3. Procedure of the Experiment

RESULTS

Pedagogical Effectiveness

The first comparison was between the performance of the post-lab exam in Group 1 and pre-lab exam in Group 2. This was a between-subject analysis. The t-test assumptions of normality, independence and equal variance were checked, and the data met all assumptions. The t-test results showed that there was a significant difference in the performance of the participants in solving the difficult questions. After finishing the multimodal lab, participants in Group 1 were able to solve more of the five difficult questions correctly (M=3.6, SD=0.71) than those in Group 2 (M=3.0, SD=0.44), t (18) =1.77, *p*=0.047. The number of easy questions correctly solved was not significantly different. Both groups answered most of the five easy questions correctly (M=4.6, SD=0.51 for Group 1 and M=4.3, SD=0.94 for Group 2).

The second comparison was performed to identify any differences in the exam performance caused by having a multimodal lab for the same individuals. This comparison was used to provide supplementary information to the first set of comparisons. The second comparison was performed by comparing the performance on the pre- and post-lab exams for Group 2 participants. Paired t-test results showed that participants were able to solve more of the difficult problems correctly after the lab (M=3.5, SD=0.71) than before the lab (M=3.0, SD=0.67), t (18) =2.24, *p*=0.03. No significant difference existed between the number of easy problems correctly solved during the post-lab exam (M=4.1, SD=0.88) and the pre-lab exam (M=4.3, SD=0.95).

Results from both comparisons showed that experience of the multimodal lab increased the number of difficult problems correctly solved by the participants. It suggests that the multimodal lab assists in the assimilation of the knowledge taught and facilitates deeper understanding of the concepts.

Student's Attitude

At the end of the experiment, all participants filled out a survey to evaluate the multimodal lab experience. The survey used a 5-point Likert scale, with one representing the negative end and five representing the positive end. The participants' experiences with the multimodal lab were collected, including the ratings of the effectiveness of the haptic device in teaching statics concepts, the motivation for learning statics concepts, and effectiveness of the lab in developing the problem-solving skills etc. (see Table 1). The participants were also asked to give their comments on the design of the multimodal learning interface. All participants found both the visualization interface and haptic device easy to use after some trials. They generally thought the multimodal lab was effective in assisting and motivating learning the statics concepts. They thought the experience with the haptic device interesting, and felt that the multimodal lab was effective in developing their problem-solving skills.

Table 1. Survey Results (N=20)

Questions	Evaluated Construct	Mean(SD)
1. How effective was the beam problem in helping you learn static concepts?	Content	4.25(0.72)
2. How easy was the use of the haptic device?	Interface usability	4.50(0.51)
3. How easy was the use of the visual interface?	Interface usability	4.30(0.66)
4. How effective was the haptic device in helping you to learn Statics concepts?	Help Learning	4.20(0.77)
5. How effective was the multi-modal lab in motivating your learning of Statics?	Motivate	4.30(0.80)
6. How effective was the multi-modal lab in developing your problem-solving skills in Statics?	Develop problem-solving skills	4.15(0.81)
7. How interesting was the experience with the haptic device?	Interesting experience	4.80(0.41)

Comments and suggestions from the participants indicated that the participants would like to see this type of multimodal lab used to support the materials taught in the lecture. Some participants preferred to have the multimodal lab performed at the same time as the lecture. The participants described their experiences with the haptic device as powerful in helping them assimilate the statics concepts. Indeed, they felt that with the multimodal lab combined with the lecture, they gained understanding of the difficult concepts quickly. The participants who worked on both the pre-lab and post-lab exams commented on feeling more confident in solving the problems after completing the lab.

The comments of the participants were also useful in improving the current multimodal learning interface. Some of the comments concerned the graphical aspect of the interface and some were related to the content. For example, some participants suggested that having the ability to run and view multiple test sessions at once would allow them to compare between the previous diagrams and the current ones. Participants also suggested that being able to feel the intensity of the shear force and bending moment, rather than feeling only the applied load, might be more relevant for the learning of these concepts.

Discussion

Overall, the results of the study confirmed the positive trend found in the past research studies on haptics. The overall average rating for the survey was 4.2 out of 5, which indicated positive experiences with the multimodal lab. The multimodal lab served to improve the understanding of the statics material and spurred a real interest among the participants in the concepts taught. The results showed a significant difference in the performance with the difficult questions between the participants who took the lab and those who did not. There was no significant difference in the performance with the easy questions. The reason could be that the difficult questions were concerned with the shear and moment diagrams generated when the student applied the load. With the multimodal lab, the student recognized the link between the applied load through the haptic experiences and the changes in the diagrams through visualization. On the other hand, the easy questions were on the basic knowledge and definitions that can be easily acquired from the lecture. Consequently, the haptic experience complemented the lecture, and the best way to ensure the quality of understanding of the statics material is the combination of both.

This paper presented a pilot study of a multimodal lab used to enhance the learning of the engineering Statics courses. Our main goal was to test the educational effectiveness of the multimodal lab through comparison between exam performances of students who used the multimodal lab (post-lab exam for Group 2) and exam performances of those who did not (pre-lab exam for Group 1). The application of haptic interface was intended to provide the student chances to experience the concepts taught in the lecture closely. The results of this study suggested that the interactive multimodal learning interface was indeed useful and powerful in augmenting the understanding of the statics material, and provided a fun and engaging learning through the touch experience. Thus, this study showed that it is promising to integrate the haptic interface and device to the engineering courses.

From a practical point of view, educators must consider the resources needed to implement similar labs in their courses including time and money. The main driver of expense comes from developing the lab modules for the intended course material. In our case, one master's student spent one semester learning the concept of programming and developed the Visual C++ code for the lab. The other major expense is the investment needed to obtain the haptic devices. The PHANTOM desktop haptic device used in this study costs around $10,000, which is relatively expensive for widespread applications in engineering labs. However, much less expensive models of desktop haptic devices are commercially available. For example, the Omni haptic device costs around $1200.00 for education purposes, which has the same degree of freedom but less resolution. For learning purposes, cheaper haptic devices are more than sufficient for students to gain the benefit of the haptic experiences. It should be feasible to purchase around ten devices to equip a haptic computer lab. Once the lab is set up with the haptic device plugged in and visual interface loaded, the session takes about only 15 minutes to administer, which makes it convenient to be incorporated into an existing course as an added lab activity to enhance student learning. In addition, students can spend extended periods with the haptics device to enhance their learning experience and their grasp of the subject matter.

A limitation of this study was the small sample size and the random student volunteers from different educational backgrounds, which increased the variability in the experiment results. Another limitation of the study is that we used identical exam questions to test the student's understanding. Although same questions are commonly used in pre- and post- test method, the fact that the students in Group 2 has seen the exam questions before during Post-lab exam may had lead to improvement due to the familiarity with the exam questions, rather than due to the experiences of the multimodal lab. One plan to address this problem is to use essay questions rather than calculation questions to better fathom the students' levels of understanding of the concepts.

The satisfactory evaluation results and feedback from the students were encouraging to further enhance the learning of engineering statics and mechanics concepts by improving the design and content of the interface. Adding other parameters and more complex statics problems to the existing interface can be done as a future project. The interface could be tested on a larger sample of engineering students who are taking the relevant courses and who are more motivated to participate in the study. Another possible relevant research project that can be conducted in this field is comparing the effectiveness of the multimodal lab to physical labs in engineering courses. Indeed, labs in the engineering courses have been known for improving the understanding of the students and our study showed the same results. The next step can be exploring whether the multimodal virtual lab can achieve same or better quality of learning as the traditional engineering labs.

Bibliography

1. Srinivan, M.A., Basdogan, C., & Ho, C. H. (1999). Haptic Interactions in the real and virtual worlds, design, specification and verification of interactive systems. Eds: D. Duke and A. Puerta, Springer-Verlag Wien.
2. Jones, M.G., Andre, T., Superfine, R., Taylor, R. (2003). Learning at the nanoscale: The impact of students' use of remote microscopy on concepts of viruses, scale, and microscopy. *Journal of Research in Science Teaching*, 40, (3), 303-322.
3. Jones, M. G., Minogue, J., Oppewal, T., Cook, M., & Broadwell, B. (2006). Visualizing without vision at the microscale: Students with visual impairment explore cells with touch, *Journal of Science Education and Technology*, 15, 1573-1839.
4. Grow, D. I., Lawton, V., & Okamura, A. M. (2007). Educational haptics. *American Association for Artificial Intelligence (AAAI) 2007 Spring Symposia- Robots and Robot Venues: Resources for AI Education*.
5. Okamura, A. M., Richard, C., & Cutkosky, M. R. (2002). Feeling is believing: Using a force-feedback joystick to teach dynamic systems. *ASEE Journal of Engineering Education*, 91(3), 345–349.
6. He, X. (2003). Haptics-augmented undergraduate engineering education: implementation and evaluation. Master of Science thesis, Ohio University.
7. Felder, R. & Silverman, L. (1988). Learning and Teaching Styles in Engineering Education. *Engineering Education*, 78(7), 674-681.