AC 2011-1505: INNOVATIVE SHAKE TABLE LABORATORY INSTRUCTION: IMPLEMENTATION AND ASSESSMENT OF STUDENT LEARNING

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Classroom Implementation and Assessment on Student Learning of Innovative Shake Table Laboratory Instruction

Introduction

One of the most important challenges facing civil engineers is mitigating the severe human and economic consequences of structural dynamic responses to various large-scale excitations like earthquakes, hurricanes, and blasts. As such, hazard mitigation has been an important addition to the undergraduate civil engineering curriculum in recent years. Increasing access to this curriculum through emerging teleoperation and teleobservation technologies is an opportunity for innovating traditional civil engineering education. This paper describes the classroom implementation, and evaluates the impact on student learning, of an innovative virtual laboratory experience employed in 12 undergraduate civil engineering courses at 5 universities across the United States over a period of 4 years (2007-2010). This laboratory experience is designed to integrate the fundamental concepts of hazard mitigation into undergraduate civil engineering education by providing students with remote access to bench scale shake table lab stations.[1-3] The goal of the evaluation estimate the impact of virtual experiments on student learning, including understanding of course content and development of civil engineering skills, and to describe associations between student characteristics and patterns in student learning. We are particularly concerned with this second goal, because it relates to a large literature on inequality in the engineering field among males and females at all stages of the academic ladder.[4] In particular we document the extent to which females report learning less as a result of the shake table experiment than their male peers.

The plan of the paper is as follows. First, we briefly describe recent developments in bench scale shake tables and teleoperation and teleobservation technologies designed to allow students at institutions without shake tables to be able to perform real-time exercises in structural dynamics and earthquake engineering. Second, we introduce literature that documents aspects of gender inequality in math and science. Third, we describe the methods we employed to evaluate the impact on student learning of the virtual laboratory experience. Fourth, we present the results of the evaluation, paying particular attention to differential learning among female students in our sample. Finally, our discussion section contains a summary of what was accomplished and concludes with suggestions for future research.

Description of emerging technologies

Shake tables are traditionally used for experimental research in earthquake engineering. These instruments are capable of reproducing the motion of the ground during an earthquake, thus allowing for controlled testing of structures subjected to earthquakes. New concepts and techniques are often tested on scaled structures using shake tables before implementation on actual structures. Shake tables have been used at several universities for educating students about earthquake engineering and structural dynamics. However, few universities have shake tables and, due to testing schedules, only a handful of these universities have the freedom to provide students with access to these instruments. Moreover, "hands-on" experiments are not feasible due to the size of the equipment and the specialized training required to operate such systems safely.

Bench-scale shake tables are an ideal alternative to provide students access to such "hands-on" experiment. At this scale, students can observe earthquake responses, design and build model structures, modify their structures, measure structural responses, and reproduce several earthquake records. Furthermore, bench-scale tables are mobile enough to bring into the classroom, or even to local grade schools, for demonstrations. Thus, it is desirable to introduce experiments based on the use of bench-scale shake tables into the undergraduate curriculum. However, a relatively few number of universities have access to bench shake tables.

A partnership of the University Consortium on Instructional Shake Tables (UCIST) with the George E. Brown Network for Earthquake Engineering Simulation (NEES) has made it possible for a broader set of students and institutions to access shake tables for education and training.[i] The UCIST was formed in 1998 to strategically integrate earthquake engineering and structural dynamics into the undergraduate curriculum. UCIST, originally a consortium of 23 universities associated with the three U.S. national earthquake-engineering centers – the Pacific Earthquake Engineering Research Center (PEER), the Multidisciplinary Center for Earthquake Engineering Research (MCEER), and the Mid-America Earthquake Center (MAE) –has expanded to include over 100 institutions. This cooperative effort is expected to have a significant impact on the future direction of civil engineering education, and it is anticipated that this nationwide effort will result in widespread adoption of this approach by civil engineering educators. This program is expected to serve as a national, and international, model for integrating structural dynamics and earthquake engineering into the undergraduate curriculum. NEES is a premier cyber-environment project funded by the National Science Foundation (NSF) involving a geographically distributed network of world-class experimental facilities including cyberinfrastructure tools and a community of engineering and cross-discipline academic faculty. NEES cyberinfrastructure tools make it possible for earthquake engineering researchers to remotely participate in, and manipulate, experiments. This facilitates new testing methods, such as distributed hybrid testing, where various components of a single structural system are tested at geographically distributed sites. Video and data can be streamed in real time to laboratories and users around the country for analysis and simulation through the Real-time Data Viewer (RDV) developed by NEES.[ii]

The current evaluation study is a part of a larger project, an NSF funded Phase 2 Course, Curriculum, and Laboratory Improvement (CCLI) project. The purpose of this project, in recognition that integration of the fundamental concepts of hazard mitigation is not currently a component of traditional civil engineering education, was to increase understanding and proper preparation for curricular development on a national scale of such topics within the framework of earthquake engineering. The focus of the project is on learning fundamentals, and the cyberinfrastructure tools developed for NEES research were incorporated to enhance the learning process at the undergraduate level. In partnership with the NEES Consortium, Inc. (NEESinc), the CCLI leveraged the geographically-distributed network of world-class experimental facilities, its connecting cyberinfrastructure, and its extended community of engineering and cross-disciplinary faculty from academic programs across the nation to provide undergraduates with exceptional learning opportunities. The Phase 2 CCLI has developed over four academic years (2007-2010). In year 1 initial exercises were developed and disseminated to classrooms at the University of Washington and the University of Connecticut. The evaluation process began, which included the development of a student survey, with which the project sought to collect data on the impact of the laboratory exercises on student learning. Years 2 through 4 brought broader implementation of the exercises, which were modified as a result of early evaluations. The reach of the project has extended the implementation of shake table laboratory instruction to 26 classrooms in 8 universities across the United States.

Literature on women and engineering

A primary concern of educators in engineering is the underrepresentation of women in the math and science. Many explanations have been offered toward understanding the inequality in representation of women in engineering fields of study, academic departments, and in engineering careers. Researchers in the social sciences argue against traditional explanations that cite a paucity of the number of women with the ability to contribute to science to explain the current low rate of women's participation.[4] Rather, they note that there is strong evidence that socialization barriers contributing to impaired self-confidence and low expectations regarding the potential for success in science-related fields prevent girls from pursuing math and science at early ages. In fact, gender differences in early academic achievement are well documented.[5,6] A wide body of literature has chronicled the ways in which girls are disadvantaged within educational environments,[7] often focusing specifically on inequalities within the fields of math and science.[8] However, researchers suggest that, even for women who make it to college with aspirations toward careers in science in tact despite earlier discouragements, there are institutional and departmental cultural factors that deter these women from continuing to pursue their education in science fields.[4] The authors argue that administrative actions, specifically leadership that makes gender and minority issues a visible priority and works to revise departmental structures to emphasize collegiality, even if they do not directly affect attitudes, can affect behavior. Because this issue continues to be of utmost importance in math and science education, we pay particular attention to gender inequalities in our evaluation of shake table implementation.

Evaluation of the laboratory experience

This section of the paper describes the evaluation of the implementation of the cyberinfrastructure shake table laboratory instruction and activities developed by UCIST in partnership with NEES. Evaluation and research is a critical component of the CCLI project to improve earthquake-engineering education. We pursued on-going, formative evaluation to ensure that the project effectively achieved its goals in a timely way. The primary goals were to ensure that the exercises and cyberinfrastructure tools were employed using effective teaching strategies, to discover how students learn engineering, and to use the data to continuously improve the curriculum, thus practicing the scholarship of teaching, also known as "teaching as research." The ongoing assessment of the project's progress enabled the project leaders to make midcourse corrections to the learning experiences and materials.[iii]

The data used in this study were generated by surveys of students (N=505) clustered in 8 engineering courses in 5 universities across the United States during the academic years 2007-2010 (see Tables 1 and 2 for descriptive statistics of the sample). The results we present here are based on students who had no missing data on the variables of interest (N=451, about 89% of students who completed surveys). We surveyed five intro level courses, three intermediate level courses, and four advanced courses. About 43% of the sample is comprised of students who reported being either freshmen or sophomores. Most of the sample (79%) is made up of male students. In response to the survey item asking students to report the race/ethnicity with which they identify, 68% of the sample reported white, 18% reported Asian, and 14% chose another category. There is significant variation in the number of students and student demographics across the five institutions. For example, the sample drawn from the University of Connecticut includes 133 students, almost all of who are either freshman or sophomores and only about 13% of who are female. This contrasts with our sample from the University of Oklahoma, which is comprised of 35 students, about 6% of who are either freshmen or sophomores and about 23% of who are female. Across institutions, however, females are largely underrepresented in the courses that were included in our sample.

Results

First, we wanted to gauge how improvements to the shake tables over time may have resulted in improvements in students' learning. Second, we also wanted to document the extent to which males and females in our sample followed patterns in learning that have been documented in the literature on gender inequality in sciences in general and in engineering in particular. Third, we wanted to describe the shake table implementation in detail during the last phase of the project, 2010, using technology and survey methodology that benefited from the improvements made over the course of the project.

After participating in the remote shake table lab experiments, the students were asked to complete a survey with items that asked them to report on a variety of outcomes that we use to then estimate the impact of the shake table experience on student learning (see Table 3 for descriptive statistics). We asked students to report the extent to which they agreed that the class material and the shake tables were integrated (Integ) into the course as a whole (strongly disagree, disagree, neither agree nor disagree, agree or strongly agree), about their perceptions of the impact of the shake table on their understanding of the potential use of cyberinfrastructure in learning engineering principles (ConCI), and their perceptions of the impact of the shake table on their understanding of structural dynamics/vibrations concepts (ConSD). They were also asked to report the extent to which they agreed that the shake tables increased their ability to apply math to solve engineering problems, to use structural dynamics/vibrations terminology, to analyze and interpret data, and to work effectively with others. These four items were combined into a scale ranging from 1 to 5 where a value of 1 indicates strong disagreement, and 5 indicates strong agreement, with the notion that the shake tables increased skills relevant to success in engineering courses (Skills Scale, alpha=0.85).

Table 4 reports results of analysis that estimates differences in the average scores on learning outcomes for students who participated in our survey in the first two years of the project, and in the last two years of the project. On average students rated the integration of the shake tables into the course materials higher (Effect Size in standard deviation units=0.58, p-value<0.001), were more likely to agree that the shake tables helped in their understanding of structural dynamics (ES= 0.60, p<0.001), were more likely to agree that the shake tables helped with their understanding of cyberinfrastructure in learning engineering principles (ES=0.032, p-value<0.001), and had a higher average rating in skills relevant to success in engineering (ES=0.32, p-value<0.001). These results suggest that improvements to the technology over time significantly improved the impact of the remote shake table experience on student understanding of concepts and the development of skills in the classroom.

There was a good deal of variation across institutions in students' responses to these learning outcomes. These may reflect the variation in course composition of the students, characteristics of the instructors, variation in implementation of the shake tables, developments over time in the technology, etc. While a larger sample and a more thorough data collection effort necessary to estimate associations between all possible variables were beyond the scope of this study, we are able to partition the variance into within- and between-course components in these outcomes in order to relate individual level student characteristics (such as race/ethnicity, gender, and year of school) to patterns in learning within courses.[10] Table 5 reports these findings. These models control for whether or not the student is a freshman or sophomore, so the results can be interpreted as the change in mean score on the outcomes for females relative to males. The effect sizes are reported which give a sense of the size of the effect relative to the scale of the outcome variable (in standard deviation units). Women in our sample report lower scores on items measuring the extent to which the shake tables helped in understanding of concepts structural dynamics (ES=-0.25, p<0.10) and the development of skills (ES=-0.24, p<0.03). This may be because they were also less likely to report that the course materials and the shake table experiments were well integrated. However, women were not less likely to agree that report that the shake tables helped in understanding of cyberinfrastructure in learning engineering principles. These gender differences are concerning and are in line with past research on the different experiences that men and women have in science classrooms.

In the last phase of the project (2010) we distributed finalized surveys to students in one advanced course at UCSD (N=94) and a survey that was developed for instructors (N=1). We also interviewed the instructor. We report results here separately for this sample of students because they have benefitted from the improvements made to the technology over the course of the CCLI project (See tables X and X for results specific to this sample). Furthermore, we include more detailed information about the sample as a result of developments to the survey that were made across the phases of the project, and the inclusion of the instructor survey and interview. The purpose of reporting these results is to give the reader a deeper understanding of the advantages and limitations of using remote bench shake tables in the classroom.

Course Characteristics

The course surveyed in the fourth phase of the project was a large and advanced course in vibrations engineering. Half of the students were mechanical engineering students and half were structural engineering students. The course was required for engineering students. The university is on a quarter system, and this course lasted for one quarter.

Student Characteristics

The students from UCSD who responded to the survey were mostly male (79%), and upperclassmen (89%). Asian students comprised about 46% of the sample, which is larger than Asian student samples in the other schools, and about 37% of the students were non-Hispanic white students. Most students reported being familiar with using technology such as computer software prior to their experience using the shake tables. Almost all of the students (90%) expected to receive an A or B in the course.

Instructor Characteristics

The instructor was an assistant professor, female, white, and was familiar with shake tables prior to introducing them in her classroom.

Shake Table Implementation

The shake table was used for 1-2 sessions in this course. The use of the shake table was the same as in the shake table manual instructions, but what was expected in terms of the lab assignment was reduced to account for limited time. The instructor used the documentation that was provided with the shake tables, although it was modified to reflect the expectations she had for the lab assignment. The university is on a quarter system, so the expectations for the assignment were modified to reflect the limited time available to the instructor. The instructor reported that she had the students predict time histories for undamped and damped cases. The students were asked to use the half-power bandwidth to compute what the experimental damping, and to compare the experimental results and what was predicted. The instructor also reported providing the students with mass and stiffness characteristics of the buildings, although the values were dependent on whether the students were using the table at Purdue or at the University of Connecticut. The instructor had the students work in teams of two. Each team signed up for a time slot using the website provided. For one week, the students ran the table, gathered the data, and exported the data to use for their reports. They had a few weeks after that to prepare their assignment. The instructor did not do a demonstration of the shake tables for the students, and the students were not required to use MATLAB for the experiment.

Shake Table Evaluation

The student evaluations of the shake tables were favorable, although a non-trivial number of students were either neutral or negative in their evaluations (see Table X). While most students either agreed or strongly agreed that the shake tables helped their learning (67%), a non-trivial percentage neither agreed nor disagreed (21%), or disagreed or strongly disagreed (13%).

The reasons for this do not seem to be that the shake tables were not well integrated into the course, as most students either agreed (57.8%) or strongly agreed (14.7%) that the shake tables were well integrated into the course. Nor does the non-trivial number of neutral or negative responses seem to reflect the overall evaluations of the course, as about 73% of respondents reported agreeing or strongly agreeing that the course helped with their learning. The majority of students agreed that the shake tables were easy to operate, that the functions of the shake tables were adequate for learning about structural dynamics, and that the shake tables would be useful in other structural engineering courses. Between 55% and 65% of students reported that they agreed or strongly agreed with these aspects of the shake tables. In addition, students identified positive aspects of the shake tables, such as it being a visual aid and a practical application of engineering concepts to the real world. However, some students disagreed that the shake tables were easy to operate, adequate for learning, or would be useful in other structural engineering courses. Between 10% and 20% of students either disagreed or strongly disagreed with these aspects of the shake tables. Critiques included that the instructor did not demonstrate the technology prior to the students' usage, that the experiment was unclear, and that the procedure was "error-prone." The instructor echoed some of the student's critiques. The shake table had some malfunctions and the video was choppy. The instructor reported that this frustrated the students and limited the effectiveness of the learning experience.

> "We definitely had some issues where the shake tables…they kept crashing, or not working… [some] students didn't get to complete [the experiment] and would have to go back and schedule another time to do it so we had to add several days at the end because some groups, you know, tried three times and it kept crashing on them so there was a little bit of frustration there because it wasn't super robust, and I don't know if it's a networking issue because we are so far away, or just the way the tables are configured… but it wasn't very reliable so the user's experience wasn't as, um, smooth (laughs), I guess."

Suggested Improvements

Students identified a number of improvements to the shake tables that they would recommend. These included aspects that would clarify how to use the shake tables, such as better instructions (for example, integrating theory with the shake table experiment protocol), and an instructor demonstration. Students noted that they were confused about the data output and suggested that the output be labeled more clearly. In fact, most students reported that they agreed that the interface of the shake table needed to be improved (65%). The recommendations also included specific improvements to the technology such as including a stop button and a timer, improving the data export and saving functions, including a graph output, increasing the number of variables, and simplifying the interface. In addition, there were a number of complaints about connectivity issues (such as long lag times and excessive "timing out" issues). Some students agreed that the amount of time to access the shake table needed to be improved (47%).

The instructor suggested some improvements as well. She suggested that different kinds of modules, either fully fledged modules with instructions for lab reports or just instructor demonstrations for a full range of students would be useful to provide a wider variety of experiences. She suggested that this would be especially helpful in her case because their university has an in-house tabletop.

Understanding of Class Content

The instructor reported that the shake table fit in well with the content of the class, and provided an opportunity for the students to have a hands-on experience because the course does not have a stand-alone lab component.

> "The content is perfect. I mean, it fits really nicely and it really improves students' understanding of what's going on. I think a lot of them had a better idea of what [laughs] vibrations actually is and especially when you are dealing with data coming out at different frequencies so they were able to understand resonance and what happens, so, physically, you know, we don't have a laboratory component that goes with this class, so I think it was *really* advantageous for the students."

Students were asked to report the extent to which they agreed or disagreed that the shake tables improved their understanding of the following concepts, differential equations, structural dynamics/vibrations, cyberinfrastructure, and using MATLAB as a tool to solve engineering problems (See Table 2). About 40% of students disagreed or strongly disagreed that the shake tables improved their understanding of differential equations. Most students agreed or strongly agreed that the shake tables improved their understanding of structural dynamics and vibrations and cyberinfrastructure (about 66% and 53%, respectively). Most students disagreed, strongly disagreed, or were neutral in responding to the question of whether the shake tables helped improve their understanding of MATLAB as a tool to solve engineering problems (about 77%). The instructor reported that she did not require the class to use MATLAB because many of her students had not been introduced to MATLAB in their course sequence yet. She reported that some students who had experience with MATLAB did use it to complete the shake table lab assignment. Students reported that interpreting and analyzing the data and having a visual representation of concepts contributed to their learning of structural dynamics as a result of the shake tables. Students also reported benefiting from seeing in an experimental setting how harmonic motion did not perform as perfectly as they had expected given their perceptions from lecture material. Students were also asked to report the extent to which they agreed or disagreed that the shake tables increased the following skills, ability to apply math to solve engineering problems, ability to use cyberinfrastructure tools, ability to program in MATLAB, familiarity with structural dynamics/vibration terminology, ability to analyze data, ability to use sensors to measure vibration, and the ability to work effectively with others. Most students agreed or strongly agreed that the shake tables increased these skills (about 55% for each skill), with one exception: ability to program in MATLAB. Again, the instructor reported that she did not require the students to use MATLAB. In addition, students reported gaining skills such as general lab techniques (like writing reports), operating a shake table, using cyberinfrastructure for classroom learning, interpreting and analyzing experimental data and dataset management as a result of their experiences with the shake tables.

Discussion

In this paper we report the results from an evaluation of the implementation of a virtual laboratory experience in 8 classrooms from 5 universities. Results from the larger sample indicate that improvements to the shake table experiments were significantly associated with increases in students' perceptions that the shake tables aided in their learning. However, concerns are raised by gender inequalities in these results. The field of engineering has a long way to go to ensure that men and women benefit equally from innovative classroom experiences. In the last wave of the sample, year 4, we found that students' evaluations of the shake tables were generally favorable, however a non-trivial number of students were either neutral or negative in their evaluations. Content comprehension and skill improvement increased as a result of increased familiarity with the shake table technology and with improvements to the shake table technology and the deployment of the shake table technology over time within universities.

While improvements to the shake table technology were made over time in response to the student and instructor survey responses and instructor interviews, students and instructors in the last wave of data collection identified a number of recommended improvements to the shake tables. These included aspects that would clarify how to use the shake tables, such as the development of clearer instructions, requiring instructor demonstrations, and specific improvements to the technology such as including a stop button and a timer, improving the data export and saving functions, including a graph output, increasing the number of variables, and simplifying the interface. In addition, connectivity issues such as long lag times and excessive “timing out” issues were complaints. These issues are being resolved.

The use of cyberinfrastructure to achieve our educational goals is particularly attractive to today’s students. We anticipate the innovations and techniques for student engagement developed within this project to facilitate a wide variety of educational opportunities utilizing the latest shared cyberinfrastructure. The establishment of the educational collaboratory, combined with the lessons learned and innovations developed will also provide a model on which other cyberenvironments can base their educational and research activities.

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Tables and Figures

Table 1. Descriptive Statistics – Course level by institution

Institution	Num Courses	#Intro	#Int	#Adv
UW	4	2	0	2
UConn	3	3	0	0
OU	2	0	1	1
USC	2	0	2	0
UCSD	1	0	0	1
Total	12	5	3	4

Table 2. Descriptive Statistics – Student demographics by institution

Institution	Num Students	% Fr/Soph	% Female	% White	% Asian
UW	167	31.7%	27.5%	73.1%	18.0%
UConn	133	95.5%	13.5%	77.4%	4.5%
OU	35	5.7%	20.0%	74.3%	5.7%
USC	22	4.5%	22.7%	100.0%	0.0%
UCSD	94	11.7%	21.3%	37.2%	45.7%
Total	451	43.0%	21.3%	68.3%	18.0%

Table 3. Descriptive Statistics – Average student learning outcomes (and standard deviations)

Institution	Num Students	Avg Integ	Avg ConSD	Avg ConCI	Skills Scale
UW	167	3.04	3.09	2.70	2.98
		(0.98)	(1.03)	(1.03)	(0.83)
UConn	133	3.59	3.48	3.12	3.48
		(0.92)	(0.99)	(1.04)	(0.78)
OU	35	2.91	3.00	2.77	3.01
		(1.12)	(1.23)	(1.21)	(1.01)
USC	22	3.91	3.91	3.27	4.25
		(1.15)	(1.44)	(1.45)	(0.70)
UCSD	94	3.76	3.59	3.31	3.56
		(0.88)	(0.86)	(1.07)	(0.84)
Total	451	3.38	3.34	2.98	3.34
		(1.02)	(1.06)	(1.11)	(0.88)

Table 4. Difference in average outcomes across early project years (Y1/Y2) and later project years (Y3/Y4)

	Avg Y1/Y2	Avg Y3/Y4	Difference	T-Statistic	Effect Size in SD units
Integ	3.05	3.64	0.59*	6.33	0.58
ConSD	2.98	3.62	0.63*	6.61	0.60
ConCI	2.79	3.14	0.35*	3.38	0.32
Skills Scale	3.10	3.44	0.34*	3.52	0.39

* indicates two-taied t-test has a p-value < 0.001

Table 5. Effect of gender on student patterns of learning

	Female Coefficient	S.E.	P-value	Effect Size in SD units
Integ	-0.26	0.15	0.08	-0.25
ConSD	-0.34	0.18	0.07	-0.32
ConCI	-0.20	0.17	0.24	-0.18
Skills Scale	-0.24	0.11	0.03	-0.27

Table X. Student shake table evaluations

ASPECT OF SHAKE TABLE	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Shake tables helped learning	4.9%	7.8%	20.6%	57.8%	8.8%
Easy to operate	6.0	13.0	16.0	47.0	18.0
Adequate Functions	1.0	9.2	24.5	54.1	11.2
Useful in other courses	4.1	6.1	24.5	53.1	12.2
Overall course helped learning	8.9	4.5	12.5	62.5	11.6
Shake tables well-integrated into course	1.96	8.8	16.7	57.8	14.7

Table X. Student understanding of class content and improvement of skills

CONTENT	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Differential equations	13.4%	25.8%	36.1%	22.7%	2.1%
Structural dynamics/vibrations	1.0	13.4	18.6	58.8	8.3
Cyberinfrastructure and engineering	7.3	16.6	22.9	45.8	8.3
Understanding of MATLAB	20.6	33.0	23.7	20.6	2.1

SKILLS	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Apply math to engineering problems	6.2%	10.3%	24.7%	49.5%	9.3%
Use cyberinfrastructure tools to solve engineering problems	3.2	13.4	22.7	49.5	8.3
Program in MATLAB	11.3	31.4	33.0	19.6	4.1
Use of structural dynamics/vibrations terminology	5.2	8.3	22.7	48.5	15.5
Use of sensors to measure vibration	4.2	6.3	19.8	54.2	15.6
Work effectively with others	5.2	7.3	30.2	49.0	8.3

Appendix A

Description of shake table technology

The UCIST equipment consists of a Shaker IV system from Quanser Consulting (www.quanser.com). The shake table is a powerful tool for high fidelity and controllable reproduction of seismic motions. The bench-scale seismic simulator has a 46x46cm slip-table driven by a ball-screw mechanisms with an operating frequency of 0-20Hz, a (+/-) 7cm stroke and a peak acceleration (+/-) 1g with an 11.3kg payload. The Shaker IV interfaces with a PC through the Quanser Q4/Q8 board and is controlled using WinCon real-time software. Technical details about teleoperation implementation using NEES tools are beyond the scope of this paper.[1]

Description of educational exercises

Experiments are an effective means of introducing basic concepts in structural dynamics and earthquake engineering. Even at the undergraduate level, concepts in dynamics such as natural frequencies and mode shapes can clearly be portrayed during such experiments. To gain an understanding of the behavior of structures subjected to earthquakes, it is helpful to have the capabilities of modifying the dynamic characteristics of the test specimens, selecting different earthquake inputs, and measuring and analyzing structural responses. Students can learn these principles through the introduction of a series of "hands-on" experiments and classroom demonstrations throughout their coursework.

The experiments that have been developed for use with the bench shake tables consider structural dynamics, soil-structure interaction, bridge design, and torsional responses of structures. Most of the modules contain laboratory manuals for instructors and students, drawings for building experimental components, and sample data. A freshman level module and two senior level modules have been developed. In the freshman level module students are introduced to structural engineering topics, mathematical modeling of dynamic behavior, MATLAB simulation tools, and NEES capabilities and research through a series of 8 lectures. Then the students use the teleparticipation tools to conduct an experiment using the shake table. A one-story, single degree-of-freedom (SDOF) structure with light inherent damping is used. A linear voltage differential transducer (LVDT) is used to capture structural response data for a sinusoidal excitation. Video and data are observed and downloaded through RDV for analysis and comparisons to mathematical models. The students are introduced to structural engineering and vibration concepts as they are asked to model the structure and analytically determine the natural frequency and response at various sinusoidal excitations in a series of three homework assignments. The module culminates with the students conducting experimental tests to observe the structure's actual frequency and response to various sinusoidal excitations. The students prepare a laboratory report documenting their efforts during the module.

The first senior level module focuses on understanding both time and frequency domain behavior of discrete parameter dynamic systems. The students use the shake table to experimentally observe transient and forced vibration of a SDOF dynamic system representing a one-story building. Accelerometers are placed on the base (shaking table) and on the floor of the building. The input is a sinusoidal excitation, but the user can control the frequency and amplitude. The students use teleoperation tools to remotely control the shake table. Streaming video is available, and the students use RDV to view the data and video in real time. In this exercise the students first observe the transient response by examining the motions of a structure during startup of the table. In the second portion of the exercise the students obtain a frequency response function for the SDOF system by measuring the response of the system into a series of sinusoidal inputs at various frequencies. The input of the system is the acceleration of the base, and the output of the system is the acceleration of the floor mass. Using the resulting frequency response function the students are also required to compute damping levels. The students also compare a numerical model to the experimental data.

In the second senior module the students have a multiple degree of freedom (MDOF) system. Their objective is to design a vibration absorber for a two-story building model. The vibration absorber consists of a pendulum that can be adjusted to 'tune' it to the natural frequency of the primary system. The mass and length of the pendulum can be varied within a wide range of values. The students are provided with some information about the building before the lab, and are instructed to email their designs (length and mass) to the instructor prior to the laboratory time. The instructor sets up the pendulum according to their designs so that when they connect remotely the experiment is available for them. The students are expected to build a numerical model of the system and compare the experimental behavior of the system to the theoretical model. The students prepare a laboratory reports documenting their efforts during the two modules.

Appendix B

Survey Instruments

We developed two surveys to aid in the evaluation of the shake table technology, a student survey and an instructor survey. The student and instructor surveys have gone through a number of revisions. The final version can be offered for use to researchers or instructors not involved in this project. Some of the questions are close-ended (forced choice) and some are open-ended. The surveys are short (the student survey about 35 questions, and the instructor survey about 15 questions), and can be administered in paper-and-pencil format or as a web-based survey.

The purpose of the surveys was to get feedback on how the shake table was implemented in the classroom, student and instructor evaluations of the shake table, the contribution of the shake table to students' understanding of course content, and the associations between variation in implementation, classroom and instructor characteristics, and student-level characteristics to students' understanding of course content.

Interview Protocol

We developed a protocol for interviewing instructors who have used the shake table technology in the classroom. The interview was designed to last no more than one hour. The purpose of this interview was to get detailed information of how the instructor implemented the shake table technology in the classroom and to get feedback on perceived advantages and disadvantages to using the technology. Furthermore, the instructors are asked to identify any problems they encountered using the shake table technology.

Consent

We included a consent form at the beginning of the student and instructor surveys which described the research, described how the respondent's confidentiality would be protected, and provide contact information if respondents had any questions about the research at any time. For the most recent survey, three respondents declined to participate in the survey.

Survey Administration

The most recent data were generated in May 2010. These students were enrolled in an engineering course at the University of California-San Diego in the spring of 2010. The instructor provided the researchers with a list of email addresses for 158 students out of a total of 175 students who were enrolled in the course. An initial email invitation was sent to the list of students, inviting them to participate. Three additional reminders were sent to those who hadn't yet responded. The survey was in the field for 30 days in May 2010. We collected responses to the web-based student survey from 116 out of a possible 158 students (73%). Three of 116 declined to participate, 15 partially completed the survey, and 98 completed the survey (98/158=62%). We administered and collected only one instructor survey. We also interviewed this instructor.

Survey Software

The most recent version of the survey was created using Qualtrics survey software, which is available for use with a paid license. Qualtrics provides survey development, survey management, and data management services that allow researchers to develop and administer web-based surveys. Surveys created with this software and the data they generate can be shared across institutions that have a paid license. Qualtrics has a number of advantages, each of which improves response rates and streamlines the process of survey administration and data management.

- Each respondent can be assigned a unique identification number so they can start the survey at one time and finish at another. This makes responding to the survey more convenient for the respondents. This unique ID also allows the researcher to send tailored emails to the respondents based on their completion status.

- Qualtrics notifies the researcher if an email address fails, notes when the survey was started and when the survey was completed, and allows the researcher to send thank you emails to the respondents upon survey completion. The software maintains a record of communication with respondents.

- Once the time in the field for the survey has ended, the survey can be deactivated. The links provided to the respondents will no longer work once the survey is deactivated.

- Data generated from the survey can be downloaded in the following formats, Excel, SPSS, XML, or HTML.

Lessons Learned

- The time of day likely matters for survey responses. Qualtrics administrators suggest that link emails and follow up emails be sent during midday to maximize response rates.

- Response rates can be improved by including course name and instructor name in the subject line. This was done during follow up emails.

- Response patterns to the survey items suggested that respondents experienced survey fatigue as they moved through the survey instrument. We can either randomize the questions or blocks of questions to reduce bias in questions that are at the end of the survey.

- Alternatively, we can put the most important questions in the beginning of the survey to minimize bias in those questions.

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[i] See http://ucist.engineering.purdue.edu and http://www.nees.org for more details.
[ii] See Appendix A for technical details about the UCIST bench shake table equipment, the NEES cyberinfrastructure technology, and a description of the educational modules that have been developed by the NEES for the classroom.
[iii] See Appendix B for details about the tools used for evaluation and the development of survey instruments over the course of the evaluation.