2018 ASEE Annual Conference & Exposition
June 24–27, 2018
Salt Palace Convention Center
Salt Lake City, UT

Paper ID #21188

Evaluation of the Effectiveness of Using Mobile Learning in Engineering Dynamics and Vibrations Courses

Dr. Zhaoshuo Jiang P.E., San Francisco State University

Zhaoshuo Jiang graduated from the University of Connecticut with a Ph.D. degree in Civil Engineering. Before joining San Francisco State University as an assistant professor, he worked as a structural engineering professional at Skidmore, Owings & Merrill (SOM) LLP. As a licensed professional engineer in the states of Connecticut and California, Dr. Jiang has been involved in the design of a variety of low-rise and high-rise projects. His current research interests mainly focus on Smart Structures Technology, Structural Control and Health Monitoring and Innovative Engineering Education.

Mr. Alec William Maxwell, San Francisco State University

Alec Maxwell is currently an graduate student in the School of Engineering at San Francisco State University (SFSU). Besides actively conducting research on innovative tools for engineering education in the Intelligent Structural Hazards Mitigation Laboratory at SFSU with Prof. Zhaoshuo Jiang, he also serves the community as the President of the American Society of Civil Engineers for the SFSU chapter.

Prof. Zahira H Merchant, San Francisco State University
Dr. Philip Scott Harvey Jr., University of Oklahoma

Scott Harvey is an Assistant Professor in the School of Civil Engineering and Environmental Science at the University of Oklahoma (OU) and is a registered P.E. in Oklahoma. Since joining OU in 2014, he has taught undergraduate courses in statics, mechanics of materials, and dynamics and graduate courses in structural analysis and structural dynamics. Prof. Harvey has a particular interest in hands-on educational demonstrations to help students connect theory from class to practical applications.

Dr. Nolan Tsuchiya P.E., California State Polytechnic University, Pomona

Dr. Nolan Tsuchiya is an Assistant Professor of Mechanical Engineering at California State Polytechnic University, Pomona. Dr. Tsuchiya obtained his Ph.D. from University of California Los Angeles (UCLA in the area of Dynamic Systems and Control). Dr. Tsuchiya teaches Controls Engineering, System Dynamics, and Computer Programming courses using MATLAB/SIMULINK at California State Polytechnic University, Pomona. He is currently the advisor for the CPP Hyperloop team, Baja SAE racing team, and a co-advisor for the CPP ASHRAE club. He holds an active California PE license.

Dr. Cheng Chen, San Francisco State University

Dr. Cheng Chen is currently an associate professor in the school of engineering at San Francisco State University. His research interests include earthquake engineering, structural reliability and fire structural engineering.

Evaluation of the Effectiveness of Using Mobile Learning in Engineering Dynamics and Vibrations Courses

Abstract

Learning style changes from generation to generation. With the advancement of technologies, the current and incoming tech-savvy learners grow up with the digital world. Such technology advancement makes learning more accessible. As one of the examples, mobile learning has become a commonly accepted and embraced concept among the younger generations.

Effective learning occurs when the teaching styles align well with the learning styles. To better serve the need of the next-generation learners in a more accessible way, a standalone mobile learning module was recently developed for dynamics and vibration courses at San Francisco State University (SFSU). The developed mobile learning module consisted of three interconnected components, namely Analysis, Simulation and Experiment, representing the three important elements in a good engineering learning environment - theory, practical example and physical experimentation. In addition to deliver the theoretical knowledge and animated simulations in the interactive Apps, the module features a mobile remote shake table laboratory which provides students the opportunity to remotely participate and conduct physical shake table experiments in real-time through smart mobile devices (e.g. smartphones and tablets).

The results from a pilot implementation at SFSU were very encouraging. To further evaluate its effectiveness in a larger scale, the mobile learning module is implemented in three dynamics and vibration classes in three different universities. The classes are carefully selected to evaluate the adaptability and expandability of the module and its effectiveness in advancing the learning of students from various backgrounds and knowledge levels (junior, senior, undergraduate, small size, and large size class). Three measures namely Smart Tablet Readiness Measure, Engineering Concepts Achievement Test, and Engineering Concepts Self-Efficacy Test, are developed to perform the evaluation. Results clearly demonstrated the student readiness of using mobile device as a tool for learning activities, and that the mobile learning module can improve students' knowledge competence and has great potential in increase students' self-efficacy.

Introduction

Student learning style evolves with time [1, 2]. Gioia and Brass [3] in 1985 noted that the college students being taught then were a "TV Generation", who were raised in an environment dominated by visual images. In early 2000, the new "Virtual Generation" appeared with prevalent virtual media such as Internet and videogames [4]. Most recently, the "iGeneration" has been raised with the presence of mobile and handheld technologies (iPod, iTunes, iPhone, Wii, iPad) experienced in an individualized manner [5, 6]. While it may not be necessarily a single or even dominant learning style for any generation of students, it is necessary to understand what the need for the current and upcoming generations is. The current and incoming tech-savvy learners grow up with the digital world. The advancement of technologies makes learning more accessible. Mobile learning has become a commonly accepted and embraced concept among the younger generations [7]. Keegan anticipated that mobile learning would become a harbinger of the future of learning [8] and the easy access to and time spent on mobile devices makes them a perfect tool to engage learners.

Engineering is a practical science. Theory, practical examples, and physical experiments are three key elements to optimize student learning [9-10]. Theoretical knowledge teaches students to organize facts and use them in a new context. Practical examples reinforce their knowledge by relating theory to real-world applications. Physical experiments are effective means to deepen students' understanding of the underlying theory. However, access to these elements, especially physical experiments, are not always available due to limitations in equipment, room capacity, scheduling, facility accessibility, laboratory time, and safety considerations. In addition, the lecture and the laboratory section are often ill-connected as they are taught by different instructors, making it difficult to keep the quality of teaching consistent among sections and to closely relate lecture and laboratory materials. Moreover, students often are not given instant feedback on their performance due to the traditional laboratory structure.

In an effort to increase laboratory access for students, some educators and researchers developed virtual laboratories [11-15]. These include the simulated laboratory, in which experiments are modeled through computer simulations, and the remote laboratory, in which experiments are conducted by sending control commands remotely to a server and data is streamed back to the students' computers. Despite their strengths, these laboratories have drawbacks. The simulated laboratory does not fully replicate actual experiments due to assumptions that need to be made in the modeling process. The remote laboratory requires computers and specific software for students to participate remotely. In addition, both the remote and simulated laboratories create passive and isolated learning environments, in which the experience is confined to a computer screen and does not facilitate students' interactions and communications with the experimental setup, fellow students, and lab assistant, as is the case in the in-person laboratory [9].

Proposed solution

To overcome the limitations of the virtual laboratories in their current forms, a mobile remote shake table laboratory (mRSTLab) as shown in Fig. 1 has been developed at SFSU by harnessing the power of mobile technology and Internet of Things (IoT) [16]. This mRSTLab allows students to remotely participate and conduct physical shake table experiments in real-time through smart mobile devices (e.g. smartphones and tablets).

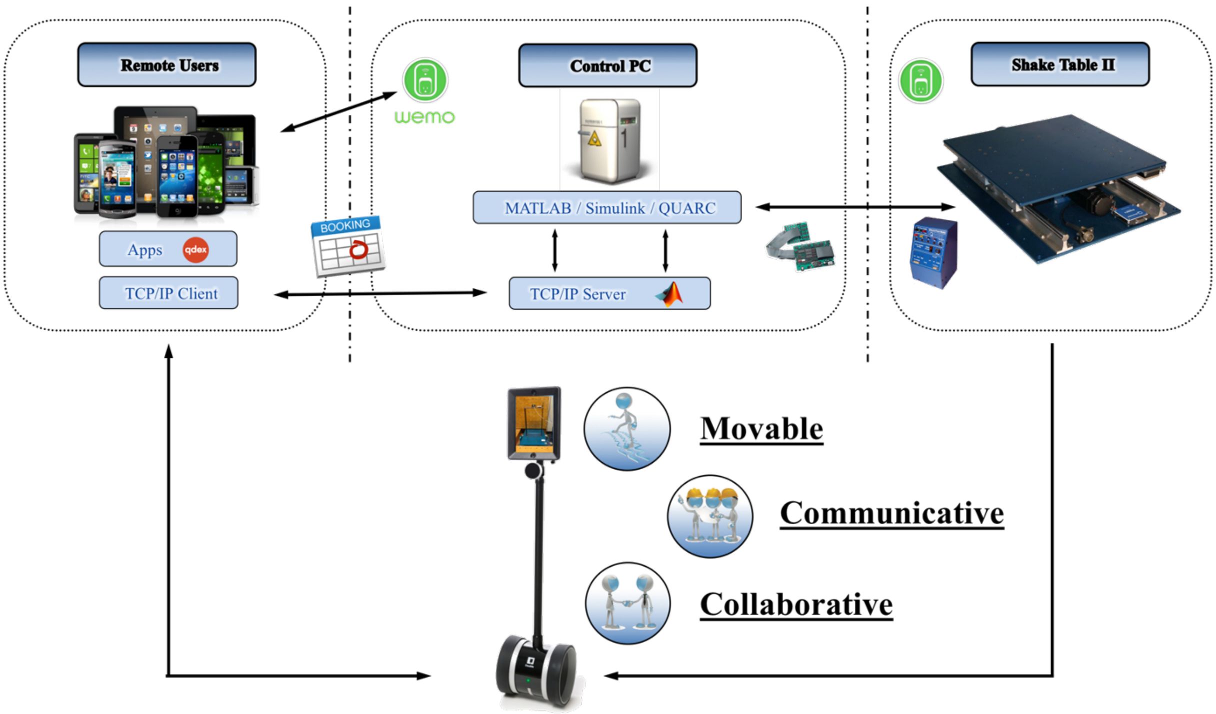

Figure 1. Schematic of the mRSTLab

Building upon the mRSTLab, a standalone laboratory module is developed for engineering dynamics and vibrations courses through interactive mobile apps, which intends to serve as a “flipped laboratory” to remove the barriers for student success without the need of sacrificing valuable class time [17]. The developed mobile module consists of three interconnected mobile apps – Analysis, Simulation, and Experiment – to teach theory, give practical examples, and conduct physical experiments. The Analysis app is designed to help students learn the necessary background theory. The Simulation app allows students to simulate the experiment to deepen their knowledge and explore new ideas in a worry-free environment; they can make mistakes without agonizing about damaging expensive equipment. The Experiment app provides students opportunity to apply their gained knowledge in a quote-on-quote in-person experiment. Artificial intelligence quizzes are integrated into the module to provide students instant feedback on their learning. Videos and instructions are embedded into the apps to guide them on the right path. Lab assistants will be accessible at assigned times to provide timely assistance. The flowchart of the learning module is shown in Fig. 2. The three components in the module can be picked and combined to fit the need for different dynamics, vibrations and earthquake engineering courses with little or no modifications.

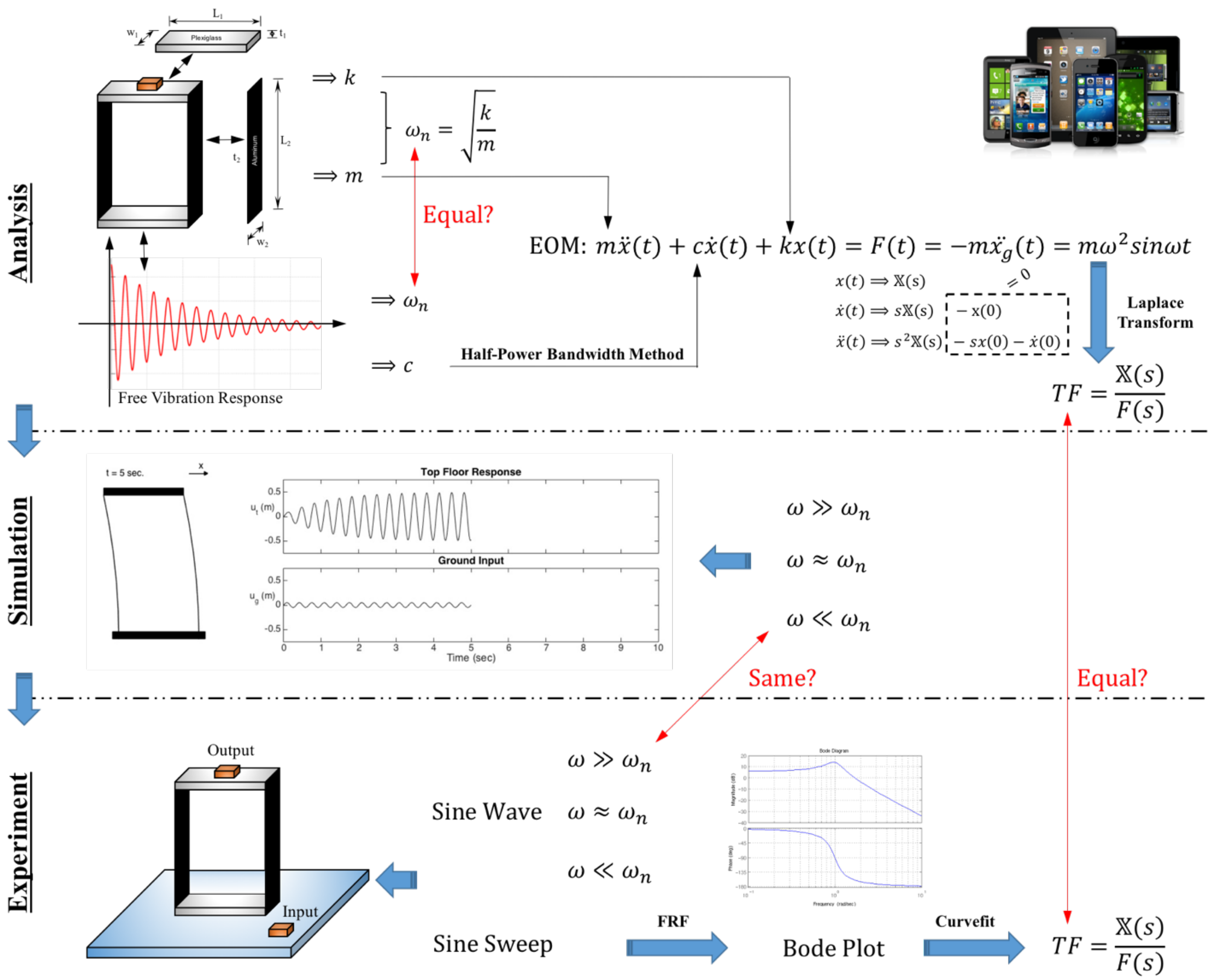

Figure 2. Mobile Learning Module for Engineering Dynamics and Vibrations Courses

Pilot study

In a pilot project, the developed mobile learning module was applied in the ENGR 461 - Mechanical and Structural Vibration, an undergraduate upper division class, at SFSU in Fall 2016 [18]. In this pilot study, students conducted physical shake table experiments through the mRSTLab with assistance of a telepresence robot, after learning the necessary knowledge in the classroom. They activated the shake table by sending control commands from the mRSTLab mobile app and observed the structure's response in real-time through the robot. In this experiment, they explored the concept of natural frequency and its effects on the structure and learned basic shake table operation principles. A telepresence robot, manufactured by Double Robotics [19], is integrated in the mRSTLab to actively engage students and provide them a real sense of in-person participation. Assisted by the robot and the lab assistant, students can set up experiments, communicate with fellow students to share thoughts and questions, observe the physical testing, and modify the experimental set-up as needed. This gives the students the feeling of being actually present in the laboratory. In this study, Pre- and post-surveys were given to students before and after the instructional intervention to evaluate the learning effectiveness of the mRSTLab. 33 of the 37 students in the class participated in the pre-survey and 21 in the post-survey. Six questions were asked in both pre- and post-surveys to assess the effectiveness of the mRSTLab in improving students' understanding of critical course concepts. The survey results are very encouraging. Students showed good improvements in learning basic engineering concepts after they used the mRSTLab. In six of the seven questions, the answer correctness increased by 8% - 21% in the post-survey compared to the pre-survey; the answer correctness in one question remained the same. The answers to the questions assessing student satisfaction revealed that, 95% of the students found the mRSTLab easy to use and felt that it was an enjoyable learning experience. 89% of the students agreed that it helped them improve their understanding of critical concepts and 84% would recommend it to a friend [18].

Multiple universities implementation

Although the pilot study shows very encouraging results, the sample size in the study is relatively small. To further evaluate the robustness of the module and its effectiveness towards student learning, the mobile learning module is implemented in three different dynamics and vibration courses at three different universities in 2017. These courses are carefully selected to evaluate the adaptability and expandability of the module and its effectiveness in advancing the learning of students from various ethnic backgrounds and knowledge levels (junior, senior, small size, and large size class). Appropriate modular components are chosen to form suitable mobile learning modules for the lower and upper level undergraduate courses according to the targeted student outcomes. The following shows the description on the courses where the module is implemented. For the purposes of maintaining the confidentiality, we will refer to the three universities as A, B, C and the corresponding courses as Course 1, Course 2 and Course 3, respectively.

University A (Course 1 – Fall 2017): Course 1 is a junior level required course for all Architectural Engineering (AE) and Civil Engineering (CE) majors. Unlike undergraduate dynamics courses offered in traditional civil engineering curricula that focus solely on rigid-body dynamics, Course 1 also covers structural dynamics over the second half of the course. The learning module was implemented concurrent with this half of the course, in which students learned free and forced vibrations of structures. One unique attempt for this implementation is that appropriate modular components were chosen to form two submodules and they are released to students at different stages of the course.

University B (Course 2 – Fall 2017): Course 2 is a senior level CE course that teaches fundamentals in dynamics and vibrations as can be seen by the fact that it is a prerequisite course for five other upper division courses. The course historically has a low success rate (repeatable grades, e.g. D, F, W, in Fall 2015 were 21.2%) which greatly jeopardizes students' ability to take the subsequent courses and prevents them from graduating on time. A laboratory section would be very helpful for students to consolidate the fundamental concepts, to relate the knowledge to practical examples, and explore new ideas through experimentation, but currently the course doesn't have any lab component.

University C (Course 3 – Fall 2017): Course 3 is a junior level Mechanical Engineering (ME) core course focusing on modeling and simulation of dynamic systems. Students first learn to derive governing differential equations for dynamic systems and then analyze them in the Laplace domain. System responses are analyzed and validated using numerical simulations. The course concludes with Frequency domain analysis and a study of Bode plots. It is considered a bottleneck course because it is a prerequisite for several senior level courses, yet the non-passing grade (D, F, W) rate is historically high. The average D, F, W rate across all sections of this course over the past 7 years is 20%.

Assessment

To assess the mobile learning module to student learning, three measures, namely Smart Tablet Readiness Measure (SmartTRM), Engineering Concepts Achievement Test (ECAT), and Engineering Concepts Self-Efficacy Test (ECSET), were developed along with questions related to students' characteristics. Data obtained from both pre- and post-survey were analyzed using the Statistical Package for the Social Sciences (SPSS) [19]. A diagnostics analysis was conducted to determine data distribution and to appropriately normalize the data. A paired sample two-tailed Student's T-test was calculated for each measure (SmartTRM, ECAT, ECSET) between the pre- and post-test scores to find differences, if there were any. Herein, the outcomes from these three different universities are presented. Comparing the results across the universities is beyond the scope of this paper.

Student characteristics

In University A, 72 students were enrolled (55 CE and 17 AE) in Course 1 in the Fall 2017 semester. A total of 67 students participated in this study. Of these 67 students, there 47 males and 20 females. Most of the participants were Caucasian (47) and the rest were African American (3), Asian (5), Native American (2), more than two races (6), and others (4). A significant number of students were either in third year of college (40) or fourth year of college (23).

In University B, 33 students were enrolled in Course 2 in Fall 2017 semester. A total of 29 students participated in this study. Of these 29 students, there 18 males, 9 females and 2 preferred not to answer. Most of the participants were Asian (6) and the rest were African American (1), Caucasian (4), two or more races (3), and others (12). A significant number of students were in their fourth year of college (20) and others were either third year (4) or graduate level students (2).

In University C, 49 students were enrolled in Fall 2017 quarter and 46 of them participated in this study. Of these 46 students, there are 36 males, 9 females and 1 preferred not to answer. Most of the participants were Caucasian (10) and Asian (12) and the rest were African American (2), two or more races (3), and others (11). The remaining preferred to not answer. A majority of students (34) were in their fourth-year. There were 9 third year students and 1 second year students.

SmartTRM - The SmartTRM is a 10 questions long self-report measure to collect students' preferences on using smart mobile devices for learning through 5-7 points Likert scale.

In University A, all students participated in the surveys (67 students) were using at least one kind of smart mobile devices. Of the total participants, 52 students reported to use a smart device for entertainment either all the times or several times in a day. A similar number reported to have used the smart device for finding information online, and a total of 45 students (67%) reported to have used their smart device for learning.

In University B, of the total participants (29 students), a total of 28 students (97%) reported to have used at least one kind of smart mobile device. A total 15 students reported to have used the smart device for entertainment. A total of 24 students reported to have used at least one kind of smart device to find information online, and 16 students (55%) used the smart device to perform learning activities.

In University C, of the total participants (46 students), a total of 45 students (98%) reported to have used at least one kind of smart mobile device. A total of 31 students reported to have used the smart device for the entertainment purpose. A total of 36 students used for the purpose of finding information online, and a total of 34 students (74%) used their smart device for learning activities.

From the results, the majority of the students (100%, 97% and 98% in University A, B and C respectively) are using at least one kind of smart mobile device and there is a high percentage of students use the device for learning activities. These results demonstrated the students' prolific use of smart mobile devices and the potential of using them for learning activities.

ECAT - The ECAT is five to seven questions long four-point scale (I don't understand the statement, I understand the statement but don't know the answer, the statement is true, and the statement is false) knowledge test that will assess student learning in engineering concepts. Different courses will have different evaluation interests. All of the bold rows show instances where a statistically significant outcome was observed. Non-bolded rows show no statistical difference before and after the assignment. The questions are listed in Appendix a - d.

Table 1. University A (Course 1) - Submodule 1 ECAT T-test

Measures	**Mean Pre/Post**	**T-test**	***p* value**
Q1	0.29/0.35	-1.070	0.289
Q2	**0.44/0.65**	**-3.196**	**0.002***
Q3	**0.35/0.53**	**-2.500**	**0.015***
Q4	0.55/0.61	-0.942	0.350
Q5	0.53/0.65	-1.544	0.128

Table 2. University A (Course 1) - Submodule 2 ECAT T-test

Measures	**Mean Pre/Post**	**T-test**	***p* value**
Q1	0.77/0.79	-0.275	0.784
Q2	**0.43/0.66**	**-2.099**	**0.040***
Q3	0.44/0.39	0.725	0.471
Q4	0.46/0.56	-1.516	0.135
Q5	**0.49/0.67**	**-3.287**	**0.002***

Table 3. University B (Course 2) - ECAT T-test

Measures	Mean Pre/Post	T-test	*p* value
Q1	0.89/0.78	1.000	0.331
Q2	**0.17/0.61**	**-3.688**	**0.002***
Q3	**0.33/0.61**	**-2.557**	**0.020***
Q4	0.56/0.61	-0.369	0.717
Q5	0.50/0.61	-0.622	0.542
Q6	0.17/0.22	-0.566	0.579

Table 4. University C (Course 3) - ECAT T-test

Measures	Mean Pre/Post	T-test	*p* value
Q1	0.57/0.67	-1.071	0.290
Q2	**0.40/0.64**	**-2.677**	**0.011***
Q3	0.5/0.64	-1.432	0.160
Q4	**0.93/0.81**	**1.952**	**0.058***
Q5	0.64/0.74	-1.432	0.160
Q6	0.26/0.31	-0.628	0.534
Q7	0.45/0.60	-1.635	0.110

Five to seven questions on knowledge competence (see Appendix a – d for details) are formed for each course at universities A, B and C based on their course learning objectives and expected outcomes. As can be seen from Tables 1, 2 and 3 above, there are statistically significant difference on two out of the five questions at University A and B and C. In all these questions with statistically significant difference at University A and B, students demonstrated improvement in knowledge competence from pre- to post-test. The two items with statistically significant difference at University C, one (Q2) demonstrated improvement in knowledge competence, while the other one (Q4) showed decrease. The authors hypothesize that this question was flawed in that it fundamentally addresses the concept of System Identification, which was not explicitly covered on the mRSTLab assignment. Modification will be made in the future implementations. These results showcase the effectiveness of the mobile learning module in improving students' knowledge competence in the subject matter.

ECSET - The ECSET consists of questions adopted from a pre-validated instrument, which assess students' self-efficacy on the critical engineering concepts using a five-point Likert-type scale from strongly agree to strongly disagree [20]. In this context, self-efficacy is defined as the ability of students to learn concepts and perform tasks efficiently [21]. Due to the nature of the questions (see Appendix e – f for details), for each of the charts in Table 5-8, it is desired to see a decrease in the mean value (2^{nd} column) from pre- to post-survey on questions Q1-Q5, and an increase on questions Q6-Q7. All of the bold rows show instances where a statistically significant outcome was observed. Non-bolded rows show no statistical difference before and after the assignment.

Table 5. University A (Course 1) - Submodule 1 ECSET T-test

Measures	Mean Pre/Post	T-test	*p* value
Freq. Response - Q1	1.89/1.84	0.554	0.582
Freq. Response - Q2	**2.44/2.26**	**1.746**	**0.086***

Freq. Response - Q3	2.66/2.56	0.814	0.419
Freq. Response - Q4	**2.27/2.11**	**1.862**	**0.067***
Freq. Response - Q5	2.21/2.15	0.683	0.497
Freq. Response - Q6	**2.95/3.29**	**-2.692**	**0.009***
Freq. Response - Q7	3.37/3.39	-0.207	0.837
Dam. & Reson. - Q1	2.00/1.94	0.814	0.419
Dam. & Reson. - Q2	**2.53/2.32**	**2.732**	**0.008***
Dam. & Reson. - Q3	2.84/2.61	2.029	0.047*
Dam. & Reson. - Q4	2.39/2.23	1.601	0.115
Dam. & Reson. - Q5	2.29/2.19	1.029	0.307
Dam. & Reson. - Q6	**2.89/3.31**	**-3.608**	**0.001***
Dam. & Reson. - Q7	**2.53/3.37**	**-4.449**	**0.000***

Table 6. University A (Course 1) - Submodule 2 ECSET T-test

Measures	Mean Pre/Post	T-test	*p* value
Freq. Response - Q1	**1.85/1.64**	**2.867**	**0.006***
Freq. Response - Q2	**2.31/1.87**	**4.968**	**0.000***
Freq. Response - Q3	**2.66/2.02**	**5.579**	**0.000***
Freq. Response - Q4	**2.16/1.93**	**2.229**	**0.030***
Freq. Response - Q5	**2.16/1.85**	**3.494**	**0.001***
Freq. Response - Q6	**3.21/3.59**	**-2.889**	**0.005***
Freq. Response - Q7	3.54/3.57	-0.270	0.788
Dam. & Reson. - Q1	**1.98/1.66**	**3.537**	**0.001***
Dam. & Reson. - Q2	**2.33/1.98**	**3.817**	**0.000***
Dam. & Reson. - Q3	**2.67/2.10**	**5.564**	**0.000***
Dam. & Reson. - Q4	**2.25/1.92**	**4.284**	**0.000***
Dam. & Reson. - Q5	**2.20/1.93**	**2.454**	**0.017***
Dam. & Reson. - Q6	**3.20/3.54**	**-2.789**	**0.007***
Dam. & Reson. - Q7	3.54/3.61	-0.522	0.604

Table 7. University B (Course 2) - ECSET T-test

Measures	Mean Pre/Post	T-test	*p* value
Freq. Response - Q1	1.61/1.67	-0.294	0.772
Freq. Response - Q2	2.00/1.94	0.195	0.848
Freq. Response - Q3	2.11/2.00	0.622	0.542
Freq. Response - Q4	**2.11/1.78**	**2.062**	**0.055***
Freq. Response - Q5	**2.11/1.67**	**2.406**	**0.028***
Freq. Response - Q6	3.28/3.44	-0.546	0.592
Freq. Response - Q7	3.50/3.50	0.000	1.000
Dam. & Reson. - Q1	1.72/1.61	0.461	0.651
Dam. & Reson. - Q2	2.06/1.72	1.558	0.138
Dam. & Reson. - Q3	2.06/1.94	0.437	0.668
Dam. & Reson. - Q4	1.89/1.78	0.399	0.695
Dam. & Reson. - Q5	**2.17/1.72**	**2.046**	**0.057***
Dam. & Reson. - Q6	3.22/3.61	-1.511	0.149
Dam. & Reson. - Q7	3.56/3.39	0.825	0.421

Table 8. University C (Course 3) - ECSET T-test

Measures	**Mean Pre/Post**	**T-test**	***p* value**
Freq. Response - Q1	1.48/1.45	0.255	0.800
Freq. Response - Q2	1.81/1.67	1.523	0.135
Freq. Response - Q3	**2.07/1.62**	**3.522**	**0.001***
Freq. Response - Q4	1.74/1.62	1.220	0.230
Freq. Response - Q5	**1.86/1.55**	**3.117**	**0.003***
Freq. Response - Q6	3.69/3.64	0.280	0.781
Freq. Response - Q7	3.86/3.79	0.318	0.752
Dam. & Reson. - Q1	1.50/1.48	0.227	0.822
Dam. & Reson. - Q2	1.88/1.71	1.361	0.181
Dam. & Reson. - Q3	**2.07/1.67**	**2.876**	**0.006***
Dam. & Reson. - Q4	**1.90/1.64**	**2.311**	**0.026***
Dam. & Reson. - Q5	**1.90/1.64**	**2.127**	**0.040***
Dam. & Reson. - Q6	3.74/3.67	0.464	0.645
Dam. & Reson. - Q7	3.93/3.86	0.518	0.607

For University A, statistically significant difference is found on 3 out of the seven self-efficacy related items for subject matter on topics of frequency response and damping resonance in the Submodule 1 and 6 out of the seven in Submodule 2. All of these items demonstrated increase in students' self-efficacy on the critical engineering concepts. The statistical details are listed in the Tables 5 and 6. A statistically significant difference between the pre- and post-test indicates that the mobile learning module helped the students build their confidence in the subject matters.

For University B and C, an equally positive outcome is evident as there is statistically significant increase between the pre- and post-test scores on the ECSET scores in the content areas of frequency response and damping resonance.

Conclusion and future work

Learning style changes from generation to generation. Effective learning occurs when the teaching styles align well with the learning styles. To better serve the need of the next-generation learners in a more accessible way, a standalone mobile learning module was recently developed for dynamics and vibration courses at SFSU. The developed mobile learning module consisted of three interconnected components, namely Analysis, Simulation and Experiment, representing the three important elements in a good engineering learning environment - theory, practical example and physical experimentation. In addition to deliver the theoretical knowledge and important concept and animated simulations in the interactive Apps, the module features a mobile remote shake table laboratory which provides students the opportunity to remotely participate and conduct physical shake table experiments in real-time through smart mobile devices (e.g. smartphones and tablets).

To evaluate its effectiveness, the mobile learning module is implemented in three dynamics and vibration classes in three different universities during Fall 2017. Three measures namely Smart Tablet Readiness Measure (SmartTRM), Engineering Concepts Achievement Test (ECAT), and Engineering Concepts Self-Efficacy Test (ECSET), are developed to investigate students' readiness to mobile learning, and the effectiveness of the developed mobile learning in improving students' knowledge competence and self-efficacy. From the SmartTRM result, it demonstrated the students' prolific use of smart mobile devices and the potential of using them for learning activities. The ECAT results clearly showed that the mobile learning module is effective in improving students' knowledge competence in the subject matter and the ECSET results demonstrated the good potential of using the module in increase students' self-efficacy.

In this study, the outcomes from three different universities are presented. Comparing the results across these universities is ongoing, which will provide insights on the contributing factors that cause the variation in the effectiveness of the module. Implementing the mobile learning module in a graduate level course is also under planning to further evaluate the adaptability of the module to different level of courses. The authors have made a commitment to share the developed mobile learning module to the general public, free of charge. For interested parties, please visit https://tinyurl.com/mRSTLab-Manu for how to access the learning module.

Acknowledgement

The authors would like to thank the supports from The IDEA Center, the California State University Course Redesign with Technology program, and the College of Science and Engineering and the School of Engineering in SFSU in developing the remote shake table laboratory. The authors would also like to acknowledge their partners in Quanser for their supports in the development process and the supports from the faculty members from the three universities in the implementation process.

Appendix – ECAT and ECSET Questions

a. List of knowledge competence survey questions – University A Submodule 1:
    - Q1. The stiffness of the structure has a linear relationship to the structure's natural circular frequency.
    - Q2. Given the stiffness remains the same, the larger the mass is, the higher the natural circular frequency of the structure will be.
    - Q3. The damped natural circular frequency is approximately the same as the undamped natural circular frequency when the damping is small.
    - Q4. The inherent damping of a structure does not have effects on the structural free vibration response.
    - Q5. The damping ratio of the structure can be calculated from the free vibration response of the structure.

b. List of knowledge competence survey questions – University A Submodule 2:
    - Q1. In order to find the equation of motion of a structure, the calculations of mass, stiffness and damping coefficient are necessary.
    - Q2. Given the free vibration response of a single degree of freedom (SDOF) structure, its damping ratio can be calculated by using the half-power bandwidth method.
    - Q3. When the SDOF structure is being excited by its natural frequency, the amplitude of the structural response will typically be several times smaller than the excitation amplitude.

Q4. The inherent damping of a structure does not have effects on the structural response under external excitations.
Q5. When the excitation frequency is higher than the natural frequency of the SDOF structure, the response of the structure will be out of phase of the excitation.

c. List of knowledge competence survey questions – University B:
Q1. In order to find the equation of motion of a structure, the calculations of mass, stiffness and damping coefficient are necessary.
Q2. Given the free vibration response of a single degree of freedom (SDOF) structure, its damping ratio can be calculated by using the half-power bandwidth method.
Q3. When the SDOF structure is being excited by its natural frequency, the amplitude of the structural response will typically be several times smaller than the excitation amplitude.
Q4. The inherent damping of a structure does not have effects on the structural response under external excitations.
Q5. When the excitation frequency is higher than the natural frequency of the SDOF structure, the response of the structure will be out of phase of the excitation.
Q6. The acceleration response of a SDOF structure can be measured by using a strain gauge mounted on the top of the structure.

d. List of knowledge competence survey questions – University C:
Q1. A flexible beam or structure, such as a building or bridge, exhibits 2nd-order dynamics if the system has only one resonant peak.
Q2. If a system has a resonant peak in its frequency response, it is impossible to excite the system in a way that results in amplification (>1) of the output.
Q3. Regardless of the excitation frequency, the magnitude of the output of a system with 2nd-order dynamics is always less than that of the input.
Q4. It is possible to experimentally construct the Bode plots of a system if you can accurately measure the input and output signals.
Q5. If the system is subject to an impulsive input, the damping ratio can be determined by the free response.
Q6. If the excitation frequency is much larger than the resonant frequency, the magnitude of the output of a 2nd-order system approaches infinity as well.
Q7. If the excitation frequency is much larger than the resonant frequency, the phase of the output of a 2nd-order system approaches -180 degree.

e. List of self-efficacy survey questions pertaining to frequency response concepts – University A, B, and C:
Q1. I am confident that I have the ability to learn the materials about frequency response.
Q2. I am confident that I can do well on exam questions about frequency response.
Q3. I am confident that I can explain concepts on frequency response learned in this class to another person.
Q4. I am confident that I can understand topics that build on the knowledge of frequency response.
Q5. I am confident that I can do well on the lab experiment related to frequency response.
Q6. I feel like I don't know a lot about frequency response compared to other students.
Q7. I don't think I will be successful on exam questions about frequency response.

f. List of self-efficacy survey questions pertaining to damping and resonance concepts – University A, B, and C:
   Q1. I am confident that I have the ability to learn the materials about damping and resonance within a system.
   Q2. I am confident that I can do well on exam questions about damping and resonance within a system.
   Q3. I am confident that I can explain concepts on damping and resonance within a system learned in this class to another person.
   Q4. I am confident that I can understand topics that build on the knowledge of damping and resonance within a system.
   Q5. I am confident that I can do well on the lab experiment related to damping and resonance within a system.
   Q6. I feel like I don't know a lot about damping and resonance within a system compared to other students.
   Q7. I don't think I will be successful on exam questions about damping and resonance within a system.

References

[1] R. Mayer. *Learning and Instruction*. Thousand Oaks: Pearson. 2011. 26–107.

[2] G. Ragusa, S. Levonisova, and S. Huang. "The Influence of Formal and Informal Pedagogical Practices on Non-traditional College Students' Achievement and Persistence in STEM Education." *Association for the Study of Higher Education*. St. Louis, MO. 2013.

[3] D. Gioia, D. Brass. "Teaching the TV Generation: The case for observational learning," *Organizational Behavior Teaching Review*, vol.10(2), pp. 11–18. 1985.

[4] L. Proserpio, and D. Gioia, "Teaching the Virtual Generation" *Academy of Management Learning & Education*, vol. 6(1), pp. 69-80, 2007.

[5] L. Rosen, "Teaching the iGeneration," *Educational leadership* vol. 68, no. 5, pp. 10-15. 2011.

[6] T. Philip, and A. Garcia. "The importance of still teaching the iGeneration: New technologies and the centrality of pedagogy," *Harvard Educational Review*. vol. 83, no. 2, pp. 300-319.

[7] S. Jacob, and B. Issac. "Mobile learning culture and effects in higher education." *arXiv preprint*, arXiv:1410.4379. 2014.

[8] D. Keegan, "The Future of Learning: From elearning to mlearning". FernUniversität Hagen, Hagen, Germany, 2002.

[9] B. Balamuralithara , and P. Woods. "Virtual laboratories in engineering education: The simulation lab and remote lab." *Computer Applications in Engineering Education*, vol. 17, no. 1, pp.108-118, 2009

[10] N. Nersessian, "Conceptual change in science and in science education," *Synthese*, vol. 80, no. 1, pp. 163-183, 1989.

[11] G. Yong, Y. Yang, B. Spencer, and G. Lee. "Java-powered virtual laboratories for earthquake engineering education," *Computer Applications in Engineering Education* vol. 13, no. 3, pp. 200, 2005.

[12] S. Sung-Han, B. Spencer, and G. Lee. "Virtual laboratory for experimental structural dynamics." *Computer Applications in Engineering Education*, vol. 17, no. 1, pp. 80-88, 2009.
[13] E. Katsanos, O. Taskari, and A. Sextos. "A matlab-based educational tool for the seismic design of flexibly supported RC buildings," *Computer Applications in Engineering Education*, vol. 22, no. 3, pp. 442-451, 2014.
[14] S. Dyke, Z. Jiang, R. Christenson, X. Gao, and S. Courter. "Teleoperation and teleparticipation of instructional shake tables using the NEES cyberinfrastructure," In Processions of the World Forum on Smart Materials and Smart Structures Technology, Chongqing and Nanjing, May. 2007.
[15] S. Dyke, R. Christenson, Z. Jiang, X. Gao, and Z. Feinstein. "Tele-operation Tools for Bench-scale Shake Tables for Instruction in Earthquake Engineering," *Seismological Research Letters* vol. 78, no. 4, pp 460-463, 2007.
[16] Z. Jiang, and A. Maxwell, "Interactive Remote Shake Table Laboratory for Instruction in Earthquake Engineering", Proceedings of 123rd ASEE Annual Conference & Exposition, New Orleans, LA. 2016.
[17] Z. Jiang, C. Liu and A. Maxwell, "Mobile Learning Modules with Interactive Remote Shake Table Laboratory for Instruction in Engineering", Proceedings of the 9th annual International Conference of Education, Research and Innovation, Seville, Spain, 2016.
[18] A. Maxwell, Z. Jiang, and C. Chen, "Mobile Learning for Undergraduate Course through Interactive Apps and Novel Remote Shake Table Laboratory", Proceedings of 124th ASEE Annual Conference & Exposition, Columbus, Ohio, 2017.
[19] IBM SPSS Software. "IBM Analytics." IBM.com. http://www.ibm.com/analytics/us/en/technology/spss/ (accessed March 25, 2017).
[20] Witt-Rose, D. L. "Student self-efficacy in college science: An investigation of gender, age, and academic achievement." Master Thesis. University of Wisconsin-Stout, WI, 2004.
[21] D. Cervone, "Thinking about self-efficacy," *Behavior modification*, vol. 24, no. 1, pp. 30-56, 2000.