3-31-2020

Active Learning in Dynamics: Hands-on Shake Table Testing

Yu Bao
Rochester Institute of Technology

Active Learning in Dynamics: Hands-on Shake Table Testing

Amanda Bao*, Ph.D., PE

Associate Professor, Civil Engineering Technology, Rochester Institute of Technology

*: Corresponding Author, 78 Lomb Memorial Drive, ENT-3154, Rochester, NY 14623, USA

Phone: 585-475-4956, Fax: 585-475-7964, Email: axbite@rit.edu

Abstract:

Dynamics is one of the core courses in Civil Engineering Technology. The principles of dynamics apply to civil engineering practices in the areas of roadway design, bridge design, building design and seismic retrofit and rehabilitation. Students should have a functional understanding of the course materials rather than substitute numbers into the given equations. Active learning promotes hands-on learning, and has been proven to increase critical thinking and problem-solving abilities. It gets students more involved in their classes and students enjoy their classes more. In this paper, we present a hands-on active learning module using shake table testing to supplement the traditional lectures of Dynamics in order to enhance teaching and learning effectiveness. The learning outcomes include understanding basic vibrations and dynamics terminology, and modeling structural systems using single-degree-of-freedom models. Students design, build, analyze and test their scaled balsa wood building models. The shake table input motions include sinusoidal waves and four scaled earthquakes. The real-time motions of the models are recorded by a video camera. The final exam grades of the students were compared before and after the hands-on active learning module was implemented. The results show significant enhancement of students' grades as well as teaching and learning effectiveness. Feedback about the hands-on shake table testing module was also collected and analyzed, and students' feedback shows the active learning module advances their understanding of the course materials and enhances their interest in Dynamics.

Keywords: active learning, dynamics, hands-on, t-test

1. Introduction:

Active learning is a process which engages students in various activities that help advance their understanding and knowledge of a particular subject. Over the years, this process has become more technology-based, especially for the newest generation. Active learning promotes hands-on learning, and has been proven to increase critical thinking and problem-solving abilities. It gets students more involved in their classes and students enjoy their classes more. Active learning strategies have been adopted in STEM higher education for years and have been proven to be effective in many different disciplines such as Mathematics, Physics, Computer Science and Mechanical Engineering (Freeman et al. 2014, 8413; Michael. 2006, 160). Many studies have demonstrated active learning can have positive impact on students' learning effectiveness. Anderson et al. found that active learning “increased content knowledge, critical thinking and problem-solving abilities, and positive attitudes towards learning in comparison to traditional lecture-based delivery” (Anderson et al. 2005, 390-391). Thaman et al. pointed out active learning “increased enthusiasm for learning in both students and instructors” (Thaman et al. 2013, 33). Other benefits of active learning include development of graduate capabilities such as critical and creative thinking, problem-solving, adaptability, communication and interpersonal skills (Kember & Leung. 2005, 167), and improving students’ perceptions and attitudes towards information literacy (Deltor et al. 2012). Active learning strategies need to be well planned in order to engage students’ participation inside and outside classrooms. Our teaching innovation is built upon the successful teaching pedagogy, and will extend the application to a new sub-discipline within Civil Engineering Technology.

Structural Dynamics is a class typically taken by the fourth- or fifth-year Civil Engineering Technology students at Rochester Institute of Technology and involves kinematics and kinetics as well as vibrations of a structure. Dynamics lectures are typically theoretical and math-intensive, and provide some initial struggles to Civil Engineering Technology students who have not taken Calculus courses since their first year. In our teaching innovation, earthquake engineering is introduced at the end of the course with a new hands-on shake table testing active learning module to improve students’ understanding of vibrations on structures.

Shake table is an earthquake simulator ideal for teaching structural dynamics, vibration isolation, feedback control, and other control topics related to earthquake, aerospace and mechanical engineering. Users can generate sinusoidal loading, chirp loading as well as pre-loaded acceleration profiles of real earthquakes, to study their effects on buildings, bridge and other types of structures. Additionally, earthquake vibration data can be downloaded from an online Ground Motion Database.

2. Hands-on Shake Table Testing Active Learning Module:

A new active learning hands-on lab module of shake table testing was developed in 2018 and has been implemented into the course CVET-437 Principles of Dynamics in Civil Engineering Technology at Rochester Institute of Technology ever since. The module includes both class demo and small group project and testing.

The intended learning outcomes for the hands-on active learning module are:

1) Observe the effects of different stiffness and mass on the frequency of structures.
2) Observe resonance of the building.
3) Calculate the natural frequency and stiffness of the building.

The class demo project uses a 6-story comprehensive balsa wood building model simulating the real-world building as shown in Figure 1, and the building details include mini-figures and furniture on each floor to representing real loads, adjustable mass on each floor and adjustable lateral stiffness of the building. The input motions are simulated earthquake loads from the shake table. Students can change the loads and adjust the building stiffness to observe different dynamic responses of the building model. The demo model allows students to change design configurations, add bracings to enhance the building performance under earthquakes as well as developing strategies of seismic retrofit and remedial options. The building has a strong axis and a weak axis, and the two axes are orthogonal. The cross-sectional dimensions of the balsa wood column are ½-inch by ¼-inch. Therefore, the moment inertia of the strong-axis is 4 times of that of the weak axis. By changing the directions of the model on the shake table, students can observe the effect of stiffness on the building's dynamic responses to vibration and different shaking modes.

Figure 1: Demo Building Model

For the small group project, students design, build, analyze and test their building models in a group of 4 students. Students apply the vibration theories that they learn from dynamics lectures and combine their engineering knowledge to design a 2-story building that can survive the given earthquake loadings. Students are encouraged to form their groups. The story height should be between 22 cm and 25 cm, and total height of the building should be between 44 cm and 50 cm with a flat roof. The building plan dimensions are 20.3 cm (8 inches) by 20.3 cm (8 inches) with column spacing of 10.15 cm (4 inches) as shown in Figure 2. The total mass including dead load and live load should be between 0.8 kg and 1.2 kg. The entire class have about 15 models with different designs to test each year as shown in Figure 3. The students can observe and compare different dynamic behaviors of all the models. After the tests, students can discuss the lessons they have learned from seismic failures, and summarize the effective strategies for seismic design and retrofit. The new active learning module is substantial enhancement to the traditional lecture-type instruction of the course. Figure 4 shows the shake table testing setup.

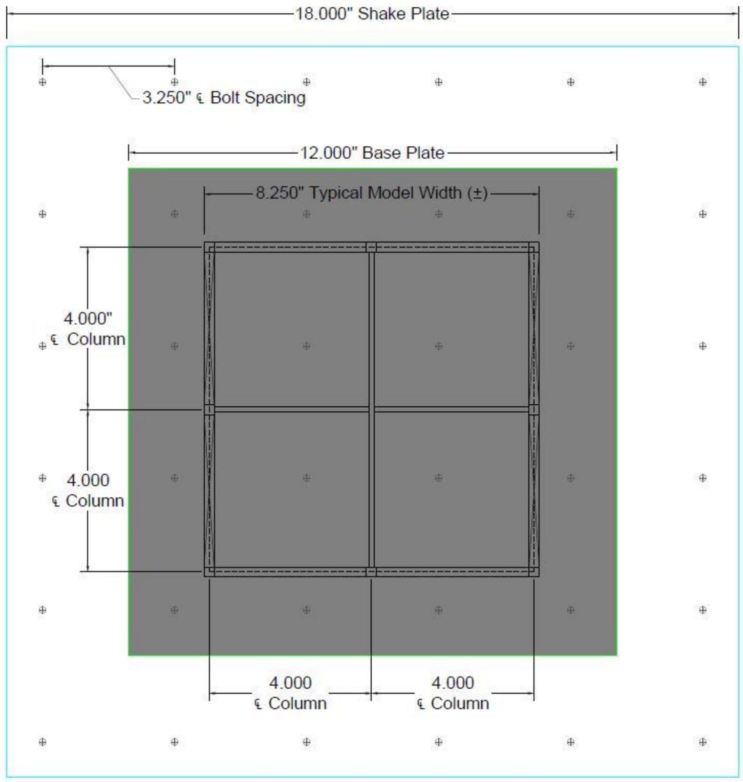

Figure 2: Base Plate and Building Plan

Figure 3: 2-Story Balsa Wood Models Built by Students

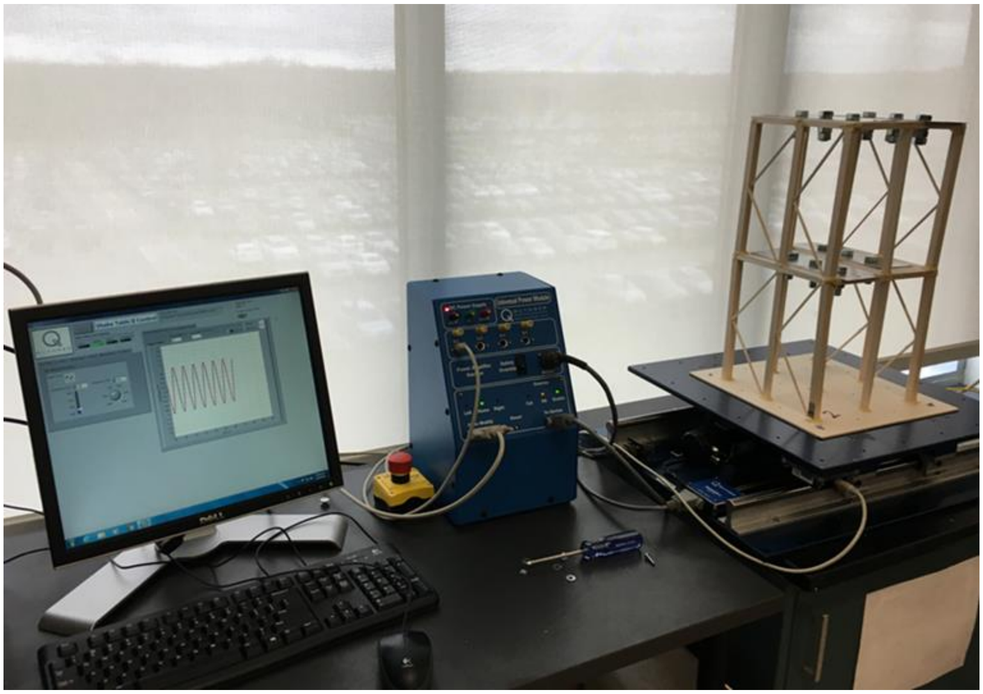

Figure 4: Shake Table Testing Setup

The input motions can be controlled by the shake table manufacturer's software, which include sinusoidal waves, chirp loading and four historical seismic events. The amplitude and frequency of the sinusoidal motion can be adjusted from 1cm to 5cm and from 1Hz to 5 Hz, respectively. Chirp loading increases its frequency from 1 Hz to 10 Hz in 10 seconds, therefore, the resonance behavior can be caught if the natural frequency of the building model falls between 1Hz and 10Hz. Four scaled seismic events including 1994 Northridge earthquake (6.7 Magnitude), 1995 Kobe earthquake (6.9 Magnitude), 1992 Mendocino earthquake (7.2 Magnitude) and 1940 El Centro earthquake (6.9 Magnitude), are the preloaded earthquake motions.

The dead load and live load on the building model is simulated by using aluminum plates with bolts and nuts on the floors and the roof as shown in Figure 1 and Figure 4. The mass at each floor and roof can be adjusted by changing the number of bolts and nuts. Students can observe different dynamic responses with various mass on their building models.

The hands-on shake table active learning module consists of design, construction, testing, data collection and analysis, and provides students with opportunities of applying theories into practice and solving engineering problems. Figure 5 shows a group of students test their building model on the shake table. Students are required to complete a lab report after the test. The lab report includes data collection and analysis as well as developing the Single-Degree-of-Freedom Model of the building. Figure 6 shows the sample data collection on the lab report.

Figure 5: Students Mounting Building Model to Shake Table

Number of Columns =

Total mass of the building including base = g = kg

Base plate mass = 180 g = 0.180 kg

Effective seismic mass = kg

Observed frequency based on resonance behavior during chirp loading, f = Hz

Natural frequency of the building, ω_n = rad/s

What is the total stiffness of the building in the lateral direction, $\sum k$ = N/m?

What is the stiffness of each column in the lateral direction, k = N/m?

The coefficient of damping c = N*s/m

Figure 6: Sample Data Collection of the Shake Table Test

3. Results:

The hands-on shake table testing module started being implemented in Spring 2018. Direct assessment of the teaching effectiveness is students' final exam grades before and after implementing the active learning module. The problems on final exams were kept the same every year from 2016 to 2019 in order to allow for appropriate comparisons. The final exams were not returned to the students and the contents were kept confidential. To minimize the impact of subjectivity in grading, the grading criteria were kept consistent over the four years. Detailed and itemized grading sheets were developed, and the points were assigned to each step of every problem. Figure 7 shows the average final exam grades of the students from Year 2016 to Year 2019 for the course CVET-437 Principles of Dynamics in Civil Engineering Technology. The grades are all out of the full points of 100.

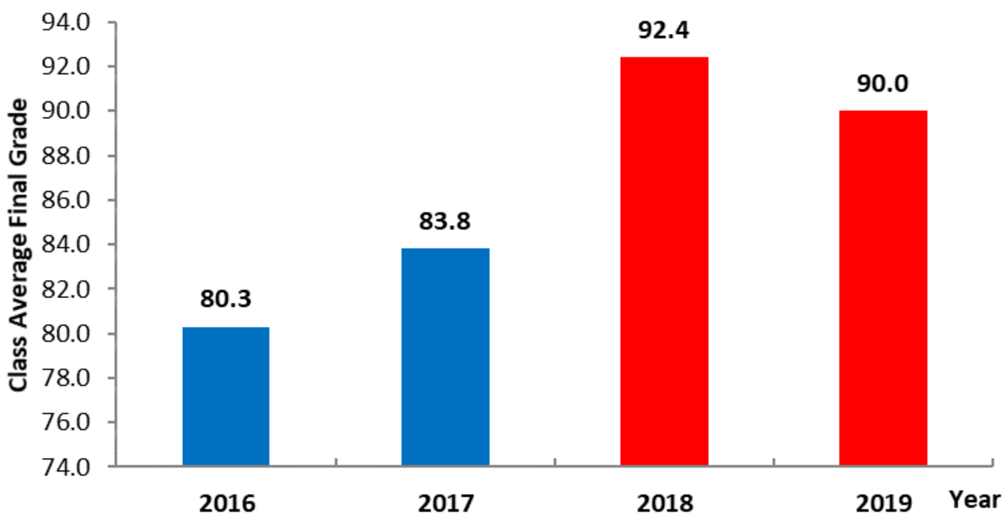

Figure 7: Class Average Final Exam Grade

Statistical analyses using unpaired t-test were performed to verify the statistical significance of the grade differences before and after implementing the hands-on active learning module. Table 1 lists the t-test results of the course "CVET-437 Principles of Dynamics in Civil Engineering Technology" before and after the hands-on shake table testing module was introduced. Average grades, standard deviations, t-values and p-values are compared from 2016 to 2019. The statistical significance of the grades before and after the active learning module was implemented are evaluated.

In a t-test, the common cutoff p-value is 0.05. If p-value is greater than 0.05, it means that the two comparison groups are not statistically significant. The differences between the two comparison groups are statistically significant when p-value is no greater than 0.05.

Table 1: Statistical Analyses for CVET-437 Final Exam Grades: Unpaired t-test Results

t-test Number	Comparison Years	Number of Students	Average Grade	Standard Deviation	t-value	p-value	Significant Different?
1	2016	64	80.30	10.719	1.7660	0.0879	No.
	2017	58	83.79	11.098			
2	2016	64	80.30	10.719	7.7082	<0.0001	Yes.
	2018	54	92.46	4.791			
3	2016	64	80.30	10.719	5.8476	<0.0001	Yes.
	2019	61	90.03	7.525			
4	2017	58	83.79	11.098	5.2983	<0.0001	Yes.
	2018	54	92.46	4.791			
5	2017	58	83.79	11.098	3.6057	<0.0001	Yes.
	2019	61	90.03	7.525			

From Table 1, in the t-test number 1, we found that before the hands-on learning modules was introduced in the course of CVET-437, the p-value between the Year 2016 and the Year 2017 is 0.0879, which is higher than the cutoff value of 0.05. It means the grade differences between the Year 2016 and the Year 2017 are not at all significant. In the t-test number 2 and 3, the grades of the Year 2016 are compared with those of the Year 2018 and the Year 2019, respectively. Both of the p-values between the Year 2016 and the Year 2018 and between the Year 2016 and the Year 2019 are less than 0.0001, which means the grade differences before and after the hands-on active learning module was implemented are significant. Consistently, in the t-test number 4 and 5, the grades of the Year 2017 are compared with those of the Year 2018 and the Year 2019, respectively. The p-values between the Year 2017 and the Year 2018 and between the Year 2016 and the Year 2019 are both less than 0.0001, which again indicates the final exam grades after the hands-on active learning module was implemented are significantly improved.

The students' online teaching evaluations related to teaching effectiveness in the course "CVET-437 Principles of Dynamics in Civil Engineering Technology" from 2016 to 2019 were collected and analyzed. The rating number 1 through 5 represents "strongly disagree", "disagree", "neutral", "agree" and "strongly agree", respectively.

The online teaching evaluation web link was sent to students by email near the end of each semester, and students were given a few weeks window to complete the online survey based on their learning experience. The online teaching evaluation questions were consistent over the four years, and students took the survey voluntarily and anonymously. Figure 8 shows students' feedback about "Advanced Student Understanding" in the course "CVET-437 Principles of Dynamics in Civil Engineering Technology" from 2016 to 2019. Students' feedback about "Enhanced Interest" in CVET-437 from 2016 to 2019 is illustrated in Figure 9.

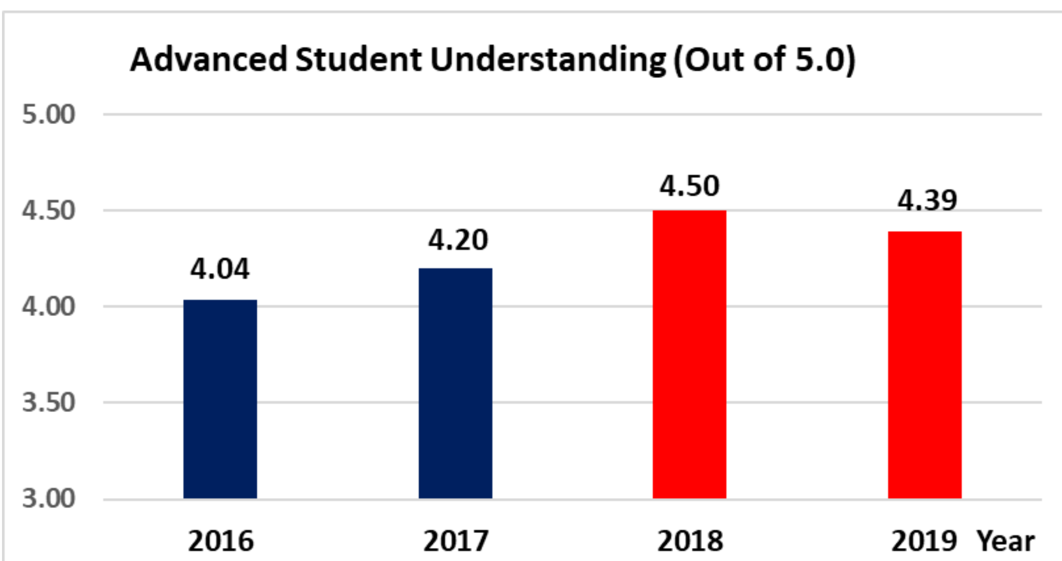

Figure 8: Teaching Evaluation of "Advanced Student Understanding"

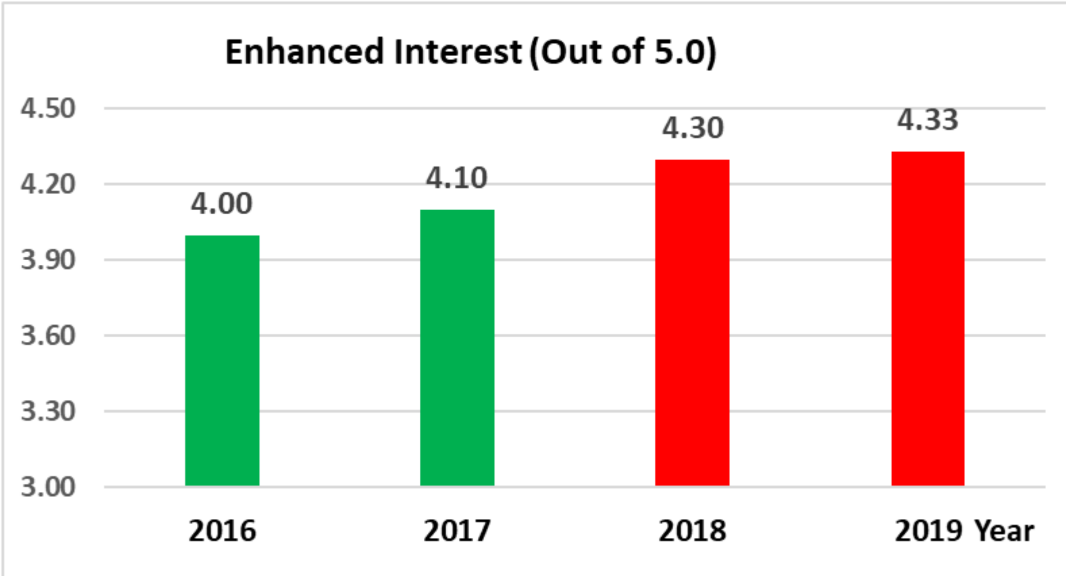

Figure 9: Teaching Evaluation of "Enhanced Interest"

4. Conclusions:

A new hands-on shake table testing active learning module has been developed and adopted in a Civil Engineering Technology Dynamics course at Rochester Institute of Technology since 2018. Both direct measurement of students' final exam grades and feedback from students' teaching evaluations show the new hands-on active learning module advances students' understanding of the course materials as well as enhances their interest in learning Dynamics.

From the results and evidence shown in Table 1 and Figures 7 through 9, we can conclude that:

1) The students' grades in Dynamics are significantly improved after the hands-on shake table testing active learning module is implemented into the course CVET-437 "Principles of Dynamics in Civil Engineering Technology".
2) The trend of students' feedback about "Advanced Student Understanding" from the teaching evaluation is consistent with that of the direct assessment of students' final exam grades. The hands-on active learning module has proven to effective to advance students' understanding of Dynamics course materials.

3) The ratings of "Enhanced Interest" get higher after the hands-on shake table testing was adopted to supplement the traditional Dynamics lectures. Students are more interested in the course materials and learn better under the active learning environment.

Some factors remained beyond the author's control, such as class enrollment numbers, students' previous academic background, the subjectivity of students' online teaching evaluations, and the like. These variables may affect the results.

5. **Acknowledgement:**

This study was supported by Rochester Institute of Technology 2018 Provost's Learning Innovation Grant (PLIG). Rochester Institute of Technology Civil Engineering Technology Students: Andrew Walker, Christopher Powell, Emilio Moran, Marquis Mark and Deondre Roseboro, helped build the 6-story class demo building model.

6. References:

[1] Freeman, Scott; Eddy, Sarah L.; McDonough, Miles; Smith, Michelle K.; Okoroafor, Nnadozie; Jordt, Hannah and Wenderoth, Mary P. 2014. "Active learning increases student performance in science, engineering, and mathematics." *PNAS* 111 (23): 8410-8415. https://doi.org/10.1073/pnas.1319030111

[2] Michael, Joel. 2006. "Where's the evidence that active learning works?" *Advances in Physiology Education* (30): 159-167. https://doi.org/10.1152/advan.00053.2006

[3] Anderson, William L.; Mitchell, Steven M. and Osgood, Marcy P. 2005. "Comparison of student performance in cooperative learning and traditional lecture-based biochemistry classes." *Biochemistry and Molecular Biology Education* 33 (6): 387-393. https://doi.org/10.1002/bmb.2005.49403306387

[4] Thaman, Richa; Dhillon, Sukhjinder; Saggar, Sanjeev; Gupta, Meenakshi and Kaur, Harkirat. 2013. "Promoting active learning in respiratory physiology – positive student perception and improved outcomes." *National Journal of Physiology, Pharmacy & Pharmacology* 3 (1): 27-34.

[5] Kember, David and Leung, Doris Y. P. 2005. “The influence of active learning experiences on the development of graduate capabilities.” *Studies in Higher Education* 30 (2): 155-170.
[6] Detlor, Brian; Booker, Lorne; Serenko, Alexander; Julien, Heidi. (2012). “Student perceptions of information literacy instruction: the importance of active learning.” *Education for Information* 29 (2): 147-161.