

AN ABSTRACT OF THE THESIS OF

Kamilah E Buker for the degree of Master of Science in Civil Engineering
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Title: Evaluation of Desktop Learning Modules in Civil Engineering
Classrooms to Promote Inductive and Interactive Learning

Abstract approved:

David S. Hurwitz

Students in undergraduate engineering programs typically do not synthesize content learned from disparate course work until the end of their final terms of college. As an example, in undergraduate civil engineering programs, transportation engineering concepts (e.g., geometric alignment, asphalt design procedures) and geotechnical engineering concepts (e.g., shear strength of soils, soil compaction) are not often integrated until senior design, if then. This Thesis was primarily concerned with improving student understanding of how soil and transportation infrastructure interact during natural hazards. Based on this focus, a transportation geotechnics DLM was developed to focus on the concept of a response spectrum. The response spectrum is an engineering design tool that tracks the response of simplified structures to external loading. Two unique models were created: one to portray the effect of varying mass and one to demonstrate the effects of varying weight. Each Response Spectrum DLM was instrumented with three axis accelerometers at the center of each mass to estimate the velocity and

position of the mass to assess the complete response spectrum system. The completed Response Spectrum DLM introduced in three separate civil engineering classrooms at Oregon State University to determine if inductive and active learning were promoted in the classroom as a result. Through the use of the DLM, it was concluded, based on in-class observation and follow-up faculty interviews, that inductive and active learning were promoted in the classroom. Furthermore, the follow-up interviews provided evidence to support the likelihood of an instructor adopting the response spectrum DLM or an alternative DLM in future classes. All three professors expressed a desire to continue using the DLM.

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Evaluation of Desktop Learning Modules in Civil Engineering Classrooms
to Promote Inductive and Interactive Learning

by
Kamilah E Buker

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APPROVED:

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Kamilah E Buker, Author

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CONTRIBUTION OF AUTHORS

Rachel Adams contributed to the explanation of the construction of the physical DLMs. Richard Slocum contributed to the implementation and explanation of the instrument package and the GUI.

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CHAPTER 1 - INTRODUCTION

Overview

In many undergraduate engineering programs, students do not synthesize content learned from multiple courses until a capstone senior design course. As an example, in undergraduate civil engineering programs, transportation engineering concepts (e.g., geometric alignment, asphalt design procedures) and geotechnical engineering concepts (e.g., shear strength of soils, soil compaction) are not often synthesized until senior design, if then. As a result, concepts learned in multiple upper-division engineering courses, as well as other required courses, often seem disparate to students. In reality, engineers are required to synthesize concepts learned in a broad number of their courses to develop creative solutions to unique problems. This will particularly be true for the engineer of the future, who will need to develop unique solutions to problems caused by climate change and increasing global population, among others.

Objectives

A synthesis of concepts sourced from seemingly disparate courses needs to occur earlier in the engineering curriculum. The *hypothesis* is that curriculum change will have multiple benefits; namely, students will learn how to become more creative problem solvers, and will be more motivated by their coursework. Desktop Learning Modules (DLMs), combined with inductive learning and interactive learning techniques, were used to test the hypothesis.

Following the foregoing hypothesis statement, there is a *research need* to understand how DLMs, coupled with inductive and interactive learning

techniques, will help students synthesize seemingly disparate course concepts. A related *educational need* is developing a community of educators who adopt evidence-based instructional practices. Accordingly, the *objective* of this Thesis is to address the identified research and educational needs by developing a novel transportation geotechnics DLM.

While the interdisciplinary field of transportation geotechnics was the focus of this Thesis, the results are transferable to other engineering domains. A particular focus was the response of transportation infrastructure to extreme events (e.g., hurricanes, earthquakes, tsunamis, floods), because engineers of the future, throughout the United States, need to learn how to protect existing infrastructure and design new infrastructure to withstand extreme loading. Within a transportation geotechnics DLM, different engineering scenarios can be replicated to help students answer important questions; for instance: What is the response of a coastal bridge during a large earthquake? How does the response of the bridge change during an ensuing tsunami? How can the bridge design change to improve its performance during natural hazards? Figure 1.1 shows four examples of transportation infrastructure systems subjected to extreme loading.

The foregoing questions exemplify how a DLM could promote an inductive learning style, whereby students first ask important questions, then physically observe a phenomenon, and finally develop the supporting theory. In addition, DLMs naturally promote interactive classrooms, where students develop important questions to be answered, and then determine the steps required to answer them with group discussion. Engineering education specialists have suggested that inductive learning is an optimal style for engineering education and that

the interactive classroom promotes retention of critical course concepts (Felder 2002).



(a)



(b)



(c)



(d)

Figure 1.1 Examples of transportation infrastructure systems subjected to extreme loading: (a) Road damage caused by soil liquefaction during the 2007 Niigata-Chuetsu Oki, Japan Earthquake (USGS 2007), (b) Entire road networks washed out during the 2012 Hurricane Sandy disaster (GEER 2014), (c) Kesen Bridge damaged during the 2011 Great East Japan Earthquake and Tsunami (Unjoh 2012), (d) Road washout from the 2015 South Carolina floods (State 2015)

The transportation geotechnics DLM represents a first step towards the meaningful incorporation of inductive and interactive learning approach in courses that include transportation geotechnics content.

Background

In an engineering classroom, inductive learning begins by engaging students with specific examples or activities and providing students with the opportunity to observe and interpret the resulting patterns; thereby, students can construct generalizable understanding (e.g., Felder and Silverman 1988). At the heart of inductive learning theory is the philosophy of constructivism, which posits that there is no objective reality (e.g., Biggs 1996); accordingly, a person must define her own reality to understand her experiences. A contrasting theory to constructivism is positivism, which states that there is an objective reality independent of human perception (e.g., Ayer 1966). The theory of positivism lends itself to deductive learning. In an engineering classroom, deductive learning requires that students learn general theory first, and then apply the theory to, for example, engineering design scenarios. Engineering courses have been traditionally taught using a deductive learning approach (Prince and Felder 2006; Felder 2012).

A literature synthesis on the effectiveness of inductive learning by Prince and Felder (2006) showed that inductive learning approaches are at least as effective, if not more effective than deductive learning approaches, for improving student learning outcomes. To understand the effectiveness of the inductive learning approach, Prince and Felder (2006) listed six common instruction techniques to promote inductive learning in engineering classrooms: (1) guided inquiry, (2) problem-based, (3) project-based, (4) case-based, (5) discovery, and (6) just-in-time teaching.

In the guided inquiry technique, the instructor poses questions and problems or provides observations, and then the students are guided to the answers or explanations by working in groups, or by classroom discussions (Lee 2012). The problem-based, project-based, and case-based techniques are similar. In the problem-based approach, the instructor provides students with a complex and often ill-defined problem, and they develop solutions by themselves, in groups, and in class discussion (Barrows and Tamblyn 1980; Yadav et al. 2011). The guided inquiry technique and the problem-based technique are similar; however, the amount of instructor guidance is usually much greater for the guided inquiry technique, and especially at first, when students are becoming acquainted with the teaching style. In addition, the guided inquiry technique is usually focused on shorter term problems (i.e., solving a small subset of problems in a class period to focus on specific student learning outcomes) whereas the problem-based approach is usually focused on longer term problems (i.e., the students work on a large problem for the entire semester, and the instructor serves as a facilitator to help the students when needed). The project-based technique requires that the students complete a project, usually with a defined final deliverable (de Graaf and Kolmos 2003). In civil engineering, capstone senior design courses are often project-based. The case-based technique requires students to analyze a case history (Kardos and Smith 1979; Srinivasan et al. 2012). The discovery-based technique is similar to the guided inquiry technique, except the students are largely self-directed (Bruner 1961). Prince and Felder (2006) recommend against the discovery-based technique for undergraduate courses, following findings from Singer and Pease (1978) that the guided inquiry technique was more effective for helping students learn new concepts. Finally, the just-in-time teaching

approach requires students to take assessment quizzes before class, and the instructor to adjust the instruction according to difficulties the students are having with the material (Novak et al. 1999).

This Thesis focused on the guided inquiry inductive learning approach to increase the impact of the work, because Prince and Felder (2006) stated that it is the easiest inductive learning approach. Accordingly, it is the most appropriate learning technique for inexperienced or traditional instructors to try first.

CHAPTER 2 – LITERATURE REVIEW

Interactive Classroom Engagement

Evidence suggests that engaging students in the learning process during a presentation – that is, motivating the students to be interactive learners – is an effective method for changing their conceptual understanding (e.g., Hake 2002; Prince 2004; Chi 2009). Interactive learning requires students to do more than passively listen. Interactive learning requires activities such as writing, discussion, and tactile problem-solving, and all the aforementioned activities engage students in higher-order thinking tasks such as analysis, synthesis, and evaluation.

Chi (2009) studied the effectiveness of three different active learning environments: active, constructive, and interactive. An active-learning environment engages students in simpler individual activities, such as taking notes or highlighting passages. A constructive-learning environment engages students in activities that are conceptually more difficult than the material students have recently learned; as an example, students may be required to combine multiple concepts to solve more complex problems without obvious solutions. Finally, in an interactive environment, students perform constructive activities in groups. This operationalization of active-learning environments is important, because Chi (2009) found that interactive activities have a greater effect on student learning outcomes than those of constructive activities, which in turn have a greater effect than those of simpler active learning activities. As defined previously, Chi's definition of an active-learning environment is not included into the definition; rather, the levels designated as constructive and interactive are included. A critical component of the active-learning classroom is the difficulty of the activities in which students engage. If the activities are too

simple, then students will not work together (Brown et al. 2009); if they are too difficult, then students will become frustrated and give up.

Kyte et al. (2010) explains that common faculty teaching tools include cooperative learning, guided discovery, problem-based learning, and active learning. Each of the tools listed share a common attribute: the student or learner at the center of this process (Kyte et al. 2010). The authors state, “active, problem-based learning, which poses generative open-ended questions in an environment where students actively participate in their own learning processes, is being used in engineering classrooms across the nation, and the results are encouraging: learner-centered teaching methods yield superior outcomes in ‘short-term mastery, long-term retention, depth of understanding of course material, acquisition of critical thinking or creative problem-solving skills, formation of positive attitudes toward the subject being taught, (and an increased) level of confidence in knowledge or skills’” (Kyte et al. 2010). The authors concluded that by running simulation experiments, students or learners have the opportunity to actively engage and therefore, develop a better understanding of the aspects of the real world that are being simulated (Kyte et al. 2010). The simulation allows the student to learn directly from the outcomes their actions produce (Kyte et al. 2010).

Desktop Learning Modules

Traditional teaching methods are continuing to produce engineering students who have difficulty understanding conceptual concepts (Burgher et al. 2013). Arasteh et al. (2013) reported that DLMs are being developed to create an educational experience in engineering that develops hands-on and problem-solving skills for students. One example of a DLM in development, described by Arasteh et al. (2013), focuses on the simulation

of cell separation in bioengineering courses. This particular DLM contains scaled down processes like shell and tube or double pipe heat exchangers for chemical engineering and hydraulic flow channels for civil engineering.

The incorporation of DLMs that target misconceptions have been demonstrated to reduce conceptual difficulties experienced by engineering students (Burgher et al. 2013). "DLMs are well accepted by students and have been shown to enhance student learning (Paul et al. 2009)". DLMs have shown success in reducing the frequency of misconceptions related to pressurized pipe flows through a straight pipe, shallow bend, and 90° miter bend, and a straight pipe with an 180° bend (Burgher et al. 2013). A control-group design was implemented with the DLM as the treatment in a civil engineering water resource class on open-channel flow, flow control and measurement. The concept inventory performance for the group that used the DLM improved 52.1 % over pre-test results (Paul et al. 2009).

Additionally, 98 % of students surveyed stated that hands-on learning with the DLM helped them recall important facts with greater ease, and 93 % stated that they had a better conceptual understanding of the topic (Paul et al. 2009). However, another study using the fluid mechanics DLM indicated that no statistical difference in gains between the control and treatment groups (Peterson et al. 2012). The authors concluded that there was a trend in improved abilities to describe abstract concepts on the material one week after the experiment (Peterson et al. 2012).

Another study evaluated the effectiveness of DLMs with associated activities and assessments (DLM&A) implemented in undergraduate engineering classes (Brown et al. 2014). Both the control and experimental

group responded to pre- and post- assessments. The control group participated in eleven interactive lecture sessions on open channel flow while the experimental group participated in nine lectures and two 50-minute sessions with the DLM&As (Brown et al. 2014). “The experimental group registered a gain of 0.57 out of 1.0 possible, with 70 % of the students achieving minimum competency, compared to a respective 0.26 gain and 39 % competency for the control group (Brown et al. 2014).” The study concluded that there was strong evidence that student’s conceptual understanding increased significantly when the DLM&A were incorporated into their learning environment (Brown et al. 2014).

As previously described, DLMs, such as the transportation geotechnics DLM developed in this Thesis, can improve the conceptual understanding of engineering students.

Transportation Geotechnics

Transportation geotechnics is a broad field, which is at the intersection of geotechnical engineering and transportation engineering. Fundamentally, transportation geotechnics is the study of how transportation infrastructure (e.g., roadways, bridges) and geotechnical materials (e.g., rock, soil) interact. Important subtopics within the field of transportation geotechnics include, but are not limited to: (1) understanding the geotechnical properties of soils, rock, or soil mixed with novel reinforcing material used as a subgrade material for transportation infrastructure, (2) the use of geosynthetics on, under, or around transportation infrastructure, (3) building embankments for transportation infrastructure such as heavy rail, (4) the relationships between the geometric design and the surrounding subgrade materials, (5) pavement design, and (6) understanding how soil and transportation infrastructure interact during

natural hazards. A particular concern during natural hazards is a phenomenon called soil liquefaction (Seed 1979). During soil liquefaction, the soil behaves as a liquid, and thus, transportation infrastructure built atop the liquefiable soil cannot be reliably supported. Ultimately, the goal of transportation geotechnics is to design and construct safer, longer-lasting, and economically viable transportation infrastructure.

Scope

This Thesis was primarily concerned with improving student understanding of how soil and transportation infrastructure interact during natural hazards. Based on this focus, the transportation geotechnics DLM focused on the concept of a response spectrum. The response spectrum is an engineering design tool that tracks the response of simplified structures to external loading. For instance, a displacement response spectrum may track the maximum displacement of many different bridge decks or elevated roadways during earthquake loading. The power of the response spectrum as a design tool is significant. It enables engineers to investigate how a wide variety of transportation infrastructure systems will respond during an earthquake. That information can help to specify the preferable alternative designs.

Based on popular structural dynamics textbook organization (e.g., Clough and Penzien 1975; Chopra 2011; Humar 2012), as well as the authors' experience, response spectra concepts are commonly taught using a deductive approach. First, the governing equation of motion and dynamic properties for a single-degree-of-freedom oscillator, which is a simplified model of the more complex transportation infrastructure components, is given to the students. The equation of motion is often derived using an $\mathbf{F} = m\mathbf{a}$ argument (i.e., Newton's second law of motion). Second, the students

learn how to solve the equation of motion, with the given dynamic properties, using a numerical methods technique, such as the central difference method. Finally, students are shown how to plot a response spectrum with the equation of motion solution they developed in the second step.

Figure 2.1 proposes one possible application of inductive learning for teaching response spectra. Students first use a response spectrum DLM to understand how earthquake loading affects transportation infrastructure. Students physically experience the simplification of complex transportation infrastructure to single-degree-of-freedom systems, and more importantly, students physically experience the limitations of this modeling assumption. The students take measurements from the DLM, and then they plot those measurements to discuss trends and observations. From the measurements, students develop the underlying theory with each other facilitated by the faculty member (i.e., the guided inquiry approach), and then the approach follows the deductive approach outlined in Figure 2.1 (as steps c, d, and e) with one very important difference. In the final step, when the response spectrum is plotted, the measurements taken during the DLM demonstration can be plotted directly on the theoretical response spectrum. Accordingly, students can further discuss why the theory and the measurements do or do not match.

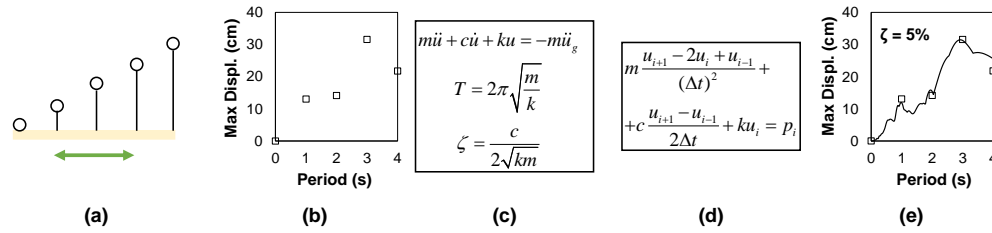


Figure 2.1 The inductive approach for teaching response spectra: (a) a DLM for simulating response spectra, (b) physical measurements from the DLM, (c) the theory behind the DLM and measurements; i.e., equation of motion and vibrational properties, (d) the numerical method used to solve the equation of motion, and (e) the displacement response spectrum

According to the foregoing discussion, the inductive approach, when considering the response spectrum example, has several key advantages. The primary advantage is that limitations of methods and deviance between theory and measurements can be discussed, which is a critical element to understanding engineering design.

According to the article entitled *Student Understanding of Sight Distance in Geometric Design* by Brock Andrews, Shane Brown, Devlin Montfort, and Michael P. Dixon, the authors found that compared to lecture-based teaching methods, interactive-engagement led to a greater improvement of student comprehension (Andrews et al. 2010). The authors defined interactive-engagement as “‘designed, at least in part, to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors’” (Andrews et al. 2010).

Summary

To maximize student-learning outcomes in transportation geotechnics, interactive learning will be promoted in engineering classrooms. Students will be tasked with working together on problems leveraging the transportation geotechnics DLM that are more difficult than those they have previously solved, and that require the synthesis of multiple concepts from transportation and geotechnical engineering.

A DLM to promote the inductive and interactive learning of response spectra for transportation infrastructure was developed. The response spectrum device was developed first because of the numerous possible alternatives and it was the most straightforward design, could be developed with the least expense, and would be widely applicable across a variety of civil engineering sub disciplines. Three graduate students, one in transportation engineering, one in geotechnical engineering, and one in geomatics engineering worked with the machine shop in the college of engineering to design and instrument high quality. Three CE faculty members implement these models in civil engineering classes at Oregon State University starting in the Fall Quarter of 2016. Through the use of the response spectrum DLM, inductive and active learning will be promoted in engineering classrooms.

CHAPTER 3 – METHODOLOGY

Research Questions

The specific research questions associated with implementing a Response Spectrum DLM in civil engineering classrooms at Oregon State University are presented in this subsection.

Inductive versus Deductive Learning

The DLM was used in three individual classrooms focused on geotechnical and structural engineering topics. The instructor designed the lesson plan and selected appropriate materials based on use of the Response Spectrum DLM. The following research questions were established to guide the assessment of inductive learning with the implementation of the Response Spectrum DLM in the classroom.

- *Research Question 1 (RQ1):* Can the response spectrum DLM promote inductive learning in the classroom?
- *Research Question 2 (RQ2):* Did the instructor use an inductive or deductive teaching approach with the response spectrum DLM?

Active versus Passive Learning

Literature suggests that DLMs can promote active learning within the classroom. The following research question was established to assess how effectively the Response Spectrum DLM promoted active learning within the classroom.

- *Research Question 3 (RQ3):* Did the Response Spectrum DLM promote active learning within the classroom?

DLMs have been used in a variety of ways in different types of classrooms. They provide a framework for developing tangible lesson plans for students studying engineering theory. The following research questions were established to guide the assessment of DLMs across content.

- *Research Question 4 (RQ4):* How did instructors choose to integrate the DLM in their classroom, and how did this integration vary from the originally conceived lesson plan?
- *Research Question 5 (RQ5):* What is the likelihood of an instructor adopting the Response Spectrum DLM or an alternative DLM in future iterations of this lesson or class?

Prototype Development

The first developed DLM visually demonstrates the response spectrum of a structure subject to earthquake loading, referred to as the response spectrum DLM (RS DLM). The RS DLM is a series of vertical springs attached to a rigid, moveable plate (Figure 3.1 right) with a spherical weight (Figure 3.1 left) attached to the uppermost location of each spring. The apparatus simulates a structure of a certain stiffness, modeled by the spring, and equivalent lumped-mass, modeled by the spherical weight, to predict the seismic response of a structure.



Figure 3.1 Development of finalized RSDs. Spherical weights were painted (left) and later applied to springs that had been welded to plates and painted (right)

To verify the proper selection of the springs used in the model, several iterations of RS DLM prototypes were developed with varying spring lengths and stiffnesses. The springs were required to be stiff enough to support the applied weights, but slender enough to act as a weightless member with respect to the modeled lumped-mass. Once the optimized spring arrangements were determined, various weights were applied to simulate lumped-mass point loads. Figure 3.2 shows a sample of the various spring and weight arrangements investigated.

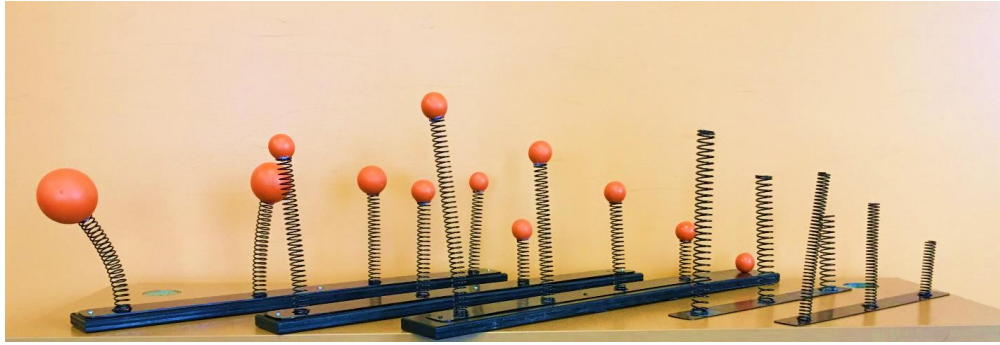


Figure 3.2 Various spring and weight arrangements investigated to determine the best configuration for the finalized RS DLMs

Ultimately, two unique RS DLMs were produced: one that could portray the effect of varying stiffness on the response of a system, and the other that could portray the effect of varying mass on the response of a system (Figure 3.3). The specifications of the two developed RS DLM components are detailed in Table 3.1. The information given in Table 3.1 could be useful for calculations necessary in classroom exercises.

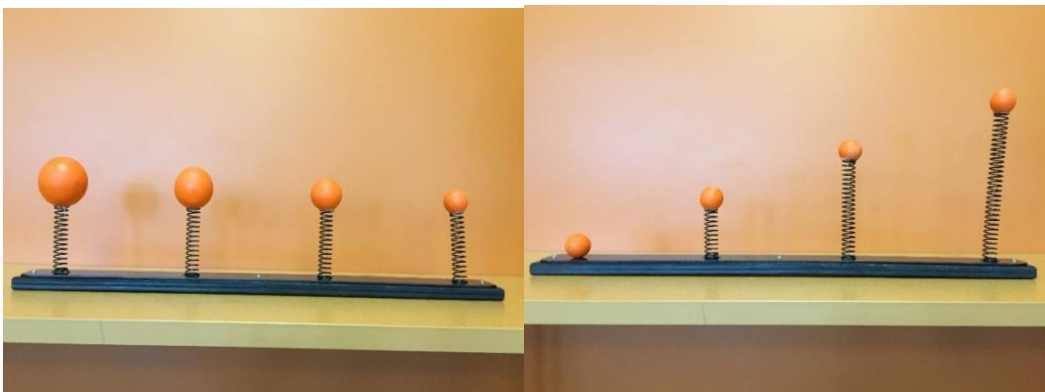


Figure 3.3 Finalized RSDs without instrumentation. The model on the left demonstrates the effect of varying structure weights and on the right the effect of varying stiffness of the structure

Fourteen finalized RS DLMs (7 varying masses, 7 varying stiffness) were built by a team of two graduate students and the machinist for the engineering department at OSU.

Table 3.1 Specifications of RS DLM components. The noted size and mass for each component was estimated from a sample set of RS DLM supplies. Each finalized model had slightly different specifications due to construction processes

Object	Size (cm)	Mass (g)	Cost
Small weight	3.1 diameter sphere	20.8	\$1.58 ea.
Medium weight	5.08 diameter sphere	47.7	\$3.45 ea.
Large weight	6.35 diameter sphere	84.4	\$8.40 ea.
Extra-large weight	7.62 diameter sphere	141.9	\$7.99 ea.
2.22 cm outer diameter spring	2.54 length segment	~5.5 (average for 2.54 cm segment*)	\$0.13 per 2.54 cm length segment

*Should add 3 grams to estimated spring mass to account for finished ends (1.5 g for each end)

Following the development of the two RS DLMs without instrumentation, initial classroom trials took place. Two Civil Engineering courses, *Structural Dynamics* (CE 534) and *Static and Dynamic Soil Behavior* (CE 577), used the RS DLMs to demonstrate phenomena already outlined in the respective course curriculum. *Structural Dynamics* and *Static and Dynamic Soil Behavior* are both graduate course that consists of approximately twenty students each. The natural period of a modeled structure was demonstrated by imposing an initial displacement on a selected spring and weight and observing the resonant frequency. The respective natural period was then compared to the remaining spring and weights and inferences were made about the trends as a function of the changing

variables. Another exercise to demonstrate earthquake loading applied a cyclic motion to the base of the apparatus and the spring and weight movements were observed. The imposed cyclic motion exposed the element that was most excitable. This observation led to the conclusion that the respective period of the applied cyclic motion corresponded to the natural period of the most excitable spring and weight component. As the frequency of the applied cyclic loading increased, additional modes could be observed in the more slender elements. The damping of the system was another observable phenomenon that was relevant to the structural response of earthquake motions.

The visible deformations and physical movements of the system are useful for aiding students in performing a qualitative analysis and developing an intuition for the response trends. The instrumentation of the RS DLM with three axis accelerometers at the center of each of the spring masses provides a data product which students can use to extend their qualitative intuition into more advanced equation and quantitative hypothesis testing. The accelerometer data can also be processed to estimate velocity and position to assess the complete response spectrum of the system. It should be noted that acceleration is measured directly through the instrument package, and although velocity and position can be calculated through integration, noise in the acceleration measurement propagates with this integration. Figure 3.4 shows a preliminary instrumented RS DLM along with the triaxle response data.

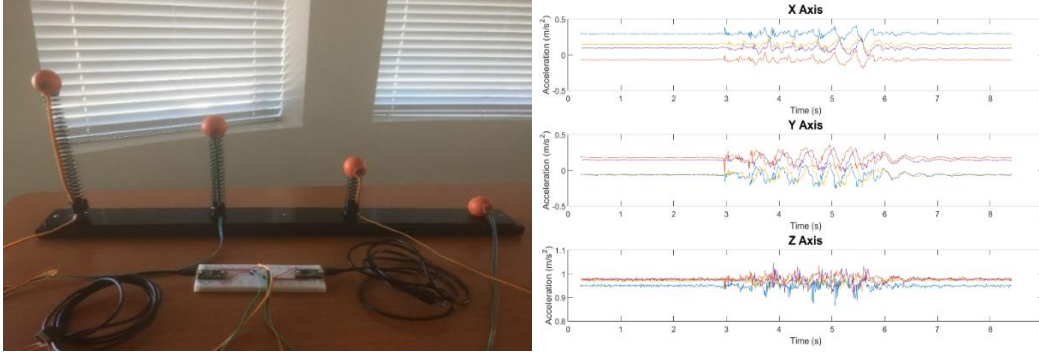


Figure 3.4 The preliminary instrumented RS DLM (left) is shown with a sample of 3-axis accelerations exerted on each of the spring masses plotted with time (right). Accelerometers fixed to the model weights record and plot the response when the device is subjected to motion.

Final Response Spectrum DLM

The final RS DLM instrumentation and acquisition software programming language were selected to ensure an open-source and low cost system so that it could be adopted by future collaborators without a large financial investment. The hardware cost of a single electronics package was \$128.48, and all of the software was free and open source. A Graphical User Interface (GUI) and command line tool were both developed for data acquisition using the Python programming language.

Electronics Package

The electronics package logs data from four, three axis accelerometers directly to a laptop or desktop PC. The accelerometers are initialized using I2C protocol and logged using two Teensy 3.2 microcontrollers, which are programmed using the Arduino IDE. The data is then transmitted from each of the microcontrollers via USB to the data logging computer via a

Serial Port. Figure 3.5 shows the proto-board diagram for the electronics package.

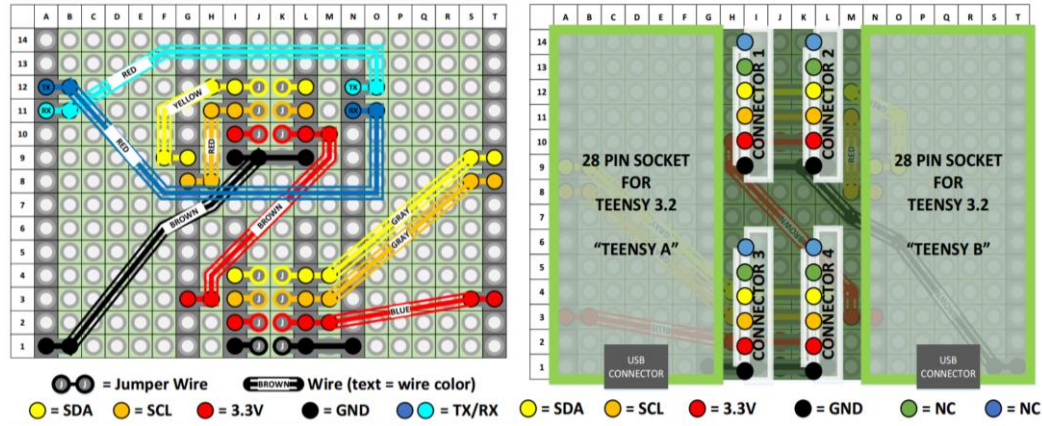


Figure 3.5 The proto-board design for each electronics package is used to interface the microcontrollers with the accelerometer connectors

The microcontrollers and accelerometers are connected to the proto-board using sockets and connectors respectively to maintain modularity of the system and improve the ease of debugging. This makes the system easier to transport between the classroom and the lab by enabling the disassembly of the system so that the electronics may be carried separately to reduce the risk of damage. Table 3.2 shows the itemized components list for each electronics package.

Table 3.2 The components for the electronics package were selected to minimize the cost of the overall system

Part	Unit Cost (\$)	Quantity	Total Cost (\$)
Accelerometer	9.95	4	39.80
Teensy 3.2 microcontroller	19.95	2	39.90
micro-USB cable	4.95	2	9.90
Ribbon Cable	4.95	1	4.95
USB Hub	6.99	1	6.99
10 Prototype Boards	3.95	1	3.95
28 Pin Socket	1.25	1	1.25
6 Wire Assembly	1.95	4	7.80
0.16 cm Heat Shrink (3.05 m)	6.99	1	6.99
Jumper Wires	6.95	1	6.95
Total			128.48

Software

The serial data is transmitted to the laptop or desktop PC via two USB COM ports. This data may be logged using numerous software packages which log COM port data streams, however all of the raw data is logged to two separate text files. To make a more seamless data logging experience for the user, two binary executables were packaged from Python code to log the data to a single text file. Python was selected as it is a free, cross platform, open source programming language commonly used by engineers. It also has a large online community, numerous open source packages, and thorough documentation.

The first Python script is a command line tool which detects a connection to the COM ports and multiplexes the data from both serial ports into one

data file. The data in this file can then be post-processed to visualize accelerations and calculate numerous response parameters. The command line tool is meant as a very barebones tool for users who only care about logging data, and not visualizing the data in real time.

A more elaborate Python script was designed to generate a GUI, which is used to visualize the data in real time while logging the data (Figure 3.6). The foundation for the GUI is built using the cross-platform modules PyQt and pyqtgraph, so that linux and mac users will also be able to run the software. The GUI contains an “interactive legend” which enables users to customize which variables are being plotted using the checkboxes. The user can also vary the color and line width of the plotted variables to optimize a custom visualization in a classroom setting to assist in highlighting a specific response. Control of data acquisition and saving is performed by clicking the “Start”, “Stop”, and “Save” buttons in the lower right of the GUI.

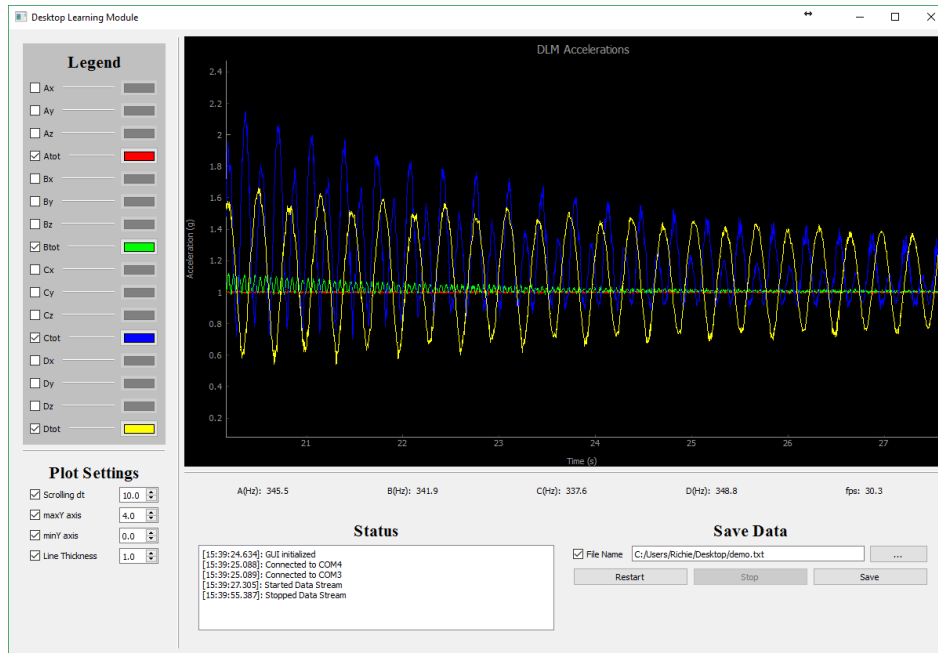


Figure 3.6 The Python GUI for data acquisition visualizes the accelerometer data in real time

Both the command line tool and the GUI have been packaged to a windows binary executable so that users can run the software with no external dependencies or installation required.

The development and instrumentation of the RS DLMs has been thoroughly documented on Github (https://github.com/OSU-Geomatics/OregonState_DLM) and shared with academic colleagues to serve as the central repository for access to and continued development of the RS DLMs. Github serves as a platform for the collaborative, open-source development of tools that will specifically be used to improve the usefulness of the RS DLMs via visualization and data analysis algorithms. This collaboration will augment the usefulness of the system in a classroom environment, and provide a platform to ensure the longevity and functionality of the RS DLMs.

Participants

Three instructors agreed to participate in this activity: Instructor A, B, and C. The instructors' years of experience range from six years to 27 years. The RS DLMS were used in three courses: *Design of Steel Structures*, *Seismic Design*, and *Geotechnical Earthquake Engineering*. *Geotechnical Earthquake Engineering* and *Design of Steel Structures* are both required courses in the school of Civil and Construction Engineering at Oregon State University. *Seismic Design* is an elective course. *Design of Steel Structures* is the only course that is exclusively for undergraduate students. The remaining two courses are graduate courses. *Design of Steel Structures* had fifty registered undergraduate students. *Seismic Design* had fifteen registered graduate students. Finally, *Geotechnical Earthquake Engineering* had nine registered students, two undergraduate and seven graduate.

CHAPTER 4 – RESULTS

Introduction

This chapter summarizes the analysis of implementing a RS DLM in three different civil engineering classrooms at OSU. The primary objective of this activity was to determine if inductive and active learning were promoted through the implementation of the RS DLM. Furthermore, the likelihood of an instructor adopting the RS DLM or an alternative DLM in future iterations in future classes was also considered. The following research questions were formulated to analyze whether inductive or deductive learning was promoted, if active or passive learning was promoted, and to discuss RS DLMs across content space.

- *Research Question 1 (RQ1):* Can the response spectrum DLM promote inductive learning in the classroom?
- *Research Question 2 (RQ2):* Did the instructor use an inductive or deductive teaching approach with the response spectrum DLM?
- *Research Question 3 (RQ3):* Did the Response Spectrum DLM promote active learning within the classroom?
- *Research Question 4 (RQ4):* How did instructors choose to integrate the DLM in their classroom, and how did this integration vary from the originally conceived lesson plan?
- *Research Question 5 (RQ5):* What is the likelihood of an instructor adopting the Response Spectrum DLM or an alternative DLM in future iterations of this lesson or class?

Inductive or Deductive Learning?

As stated earlier, inductive learning is where students first ask important questions, then physically observe a phenomenon, and finally develop the supporting theory. In an engineering classroom, inductive learning begins by engaging students with specific examples or activities and providing students with the opportunity to observe and interpret the resulting patterns; thereby, students can construct generalizable understanding (e.g., Felder and Silverman 1988). Based on the definition of inductive learning, classroom observations were the primary data source to address RQ1 and RQ2.

Natural Periods and the Generation of Response Spectrum Design of Steel Structures Taught by Instructor A

In the *Design of Steel Structures* class, Instructor A used the RS DLMs and an instructional shake table to teach the fundamental lesson of earthquake loads and demands and the natural period of a structure. Instructor A simulated an earthquake to demonstrate the concept of natural period using both of the RS DLMs to depict the phenomenon between structures of different masses and stiffness. Instructor A demonstrated Inductive learning through this lesson by first providing students the opportunity to observe a pattern, and by using this pattern to help them develop the supporting theory. For example, the first demonstration was of the different stiffness RS DLM on the shake table. Figure 4.1 displays the activity in action.



Figure 4.1 Different stiffness RS DLM in use in *Design of Steel Structures*

A student volunteer was asked to gradually increase the frequency (beginning at zero hertz) until one of the simulated structures responded. The tallest structure (least stiff) reacted first. As the frequency was increased a pattern was observed and developed by the students. The frequency on the shake table was increased until each of the sequential simulated structures responded. The theory of the natural period was concluded to be that at lower frequencies, structures with low stiffness will respond first because they have longer periods. For the second activity, Instructor A used the RS DLM with different masses in conjunction with the instructional shake table to help the students further develop a pattern for the natural period of structures. Figure 4.2 displays this demonstration in action.

Through this second demonstration, a similar phenomenon was uncovered with the different mass RS DLM demonstration. A low frequency excited the heaviest massed structure to respond first because it too has a longer period. The frequency of the shake table was again gradually increased to excite each of the sequential massed structures with the heaviest responding first to the lower frequencies. Figure 4.2 shows the different massed RS DLM in use.



Figure 4.2 Different massed RS DLM in use in *Design of Steel Structures*

Natural Periods and the Generation of Response Spectrum Seismic Design
Taught by Instructor B

In the *Seismic Design* class, Instructor B used the RS DLMs and an instructional shake table to teach the fundamental lesson of generating response spectrums using a single degree of freedom system. Instructor B also gravitated towards an inductive learning strategy through this lesson and demonstration by first providing the students with the opportunity to observe a pattern, and by using this pattern to help them develop the

supporting theory. Before beginning with the demonstration, Instructor B began by giving background information on the subject and providing the equations the students were about to visualize, a deductive paradigm. Instructor B did in fact use an inductive learning approach once the demonstration began. Figure 4.3 shows the equations documented on the whiteboard before the activity began.

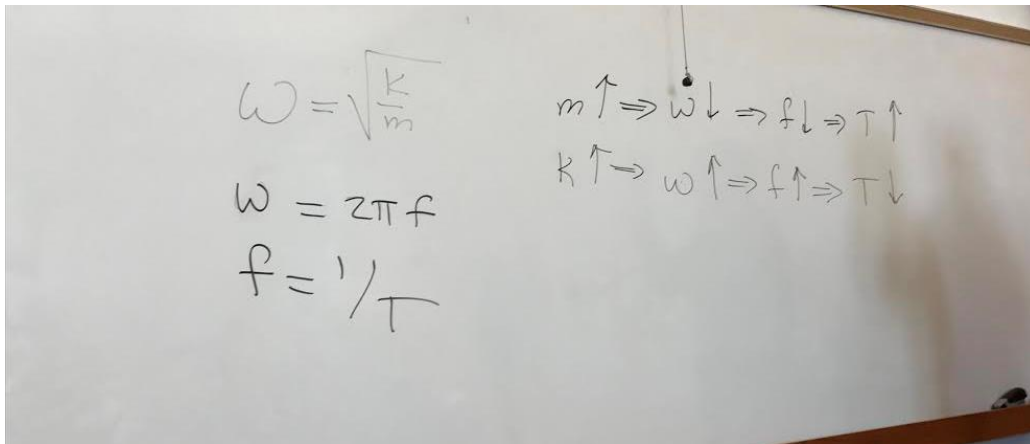

$$\omega = \sqrt{\frac{k}{m}}$$
$$\omega = 2\pi f$$
$$f = 1/T$$
$$m \uparrow \Rightarrow \omega \downarrow \Rightarrow f \downarrow \Rightarrow T \uparrow$$
$$k \uparrow \Rightarrow \omega \uparrow \Rightarrow f \uparrow \Rightarrow T \downarrow$$

Figure 4.3 Response spectra equations in *Seismic Design*

Instructor B began the demonstration with the different stiffness RS DLM. Instructor B used the shake table with the different stiffness RS DLM and increased the frequency gradually until one of the simulated structures was excited. Figure 4.4 displays the activity in action.

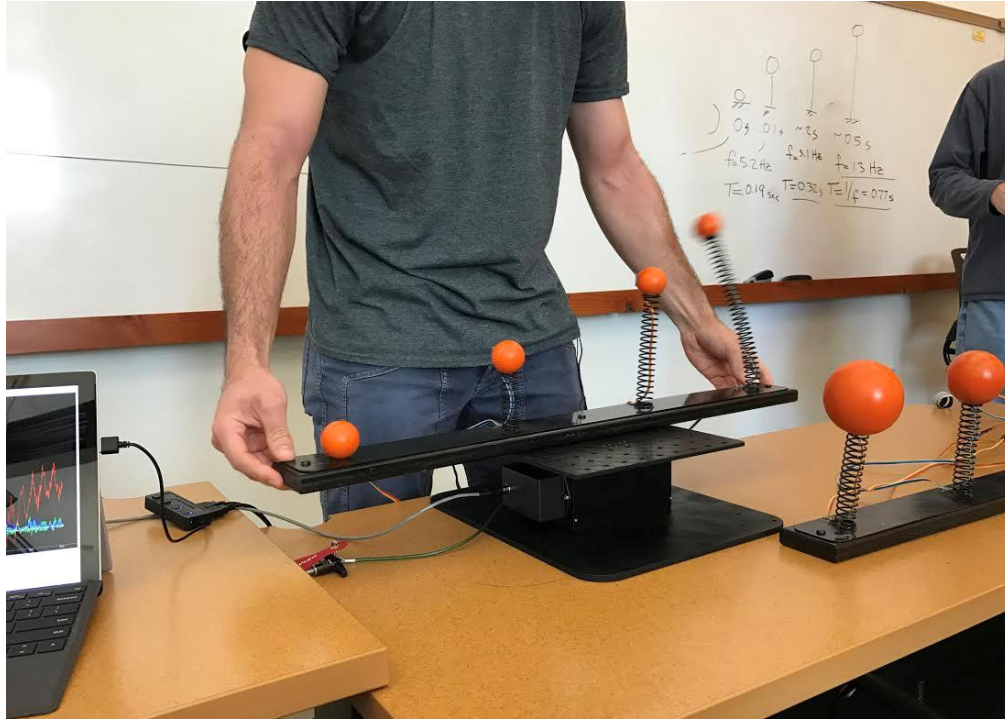


Figure 4.4 Different stiffness RS DLM in use in *Seismic Design*

Once the tallest (most flexible) structure responded, using the accelerometer software program, an estimated natural period of the spring was recorded (along with the natural frequency). A student volunteer was asked to run the shake table for this activity. The frequency of the shake table was increased until each of the sequential structures responded and each of the estimated natural periods and frequencies were recorded. As the frequency was increased a pattern was observed and developed by the students. The theory of the natural period was concluded to be that at lower frequencies, structures with low stiffness will respond first because they have longer periods. To take it a step further, Instructor B calculated the natural period of each structure using the recorded frequency. Following this calculation, the estimated periods and calculated periods were compared. A further pattern was demonstrated as the math now reflected the demonstration provided by the RS DLM: less stiff structures

have longer periods compared to stiff structures and therefore, respond to lower frequencies. Figure 4.5 depicts the calculations made by Instructor B to demonstrate the phenomenon of response spectrums and natural periods. The top row of numbers represents the estimated periods from the accelerometer software. The second row of numbers represents the recorded frequencies. Finally, the third row of numbers represent the calculated periods used for comparison purposes.

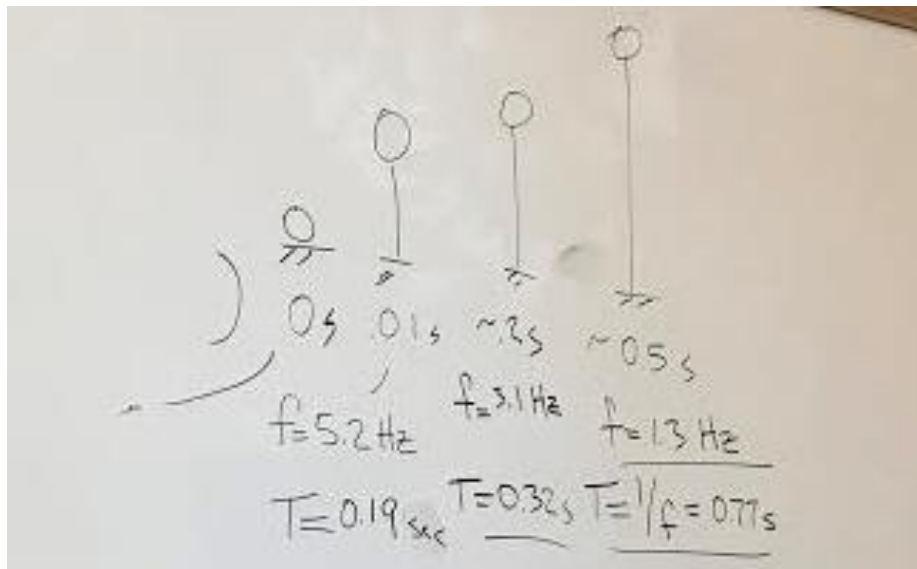


Figure 4.5 Estimated and calculated periods in *Seismic Design*

Following the calculations, Instructor B drew out the response spectrum from the calculated periods. To calculate the maximum displacement caused by an earthquake of each structure, a student volunteer was asked to simulate an earthquake using the different stiffness RS DLM by shaking it randomly. Three different students observed the structures (springs) and compared their estimated maximum displacements to determine the maximum displacement for each structure. Using the estimated maximum displacements and the calculated periods for each structure, the response spectrum was created. Figure 4.6 displays the response spectrum.

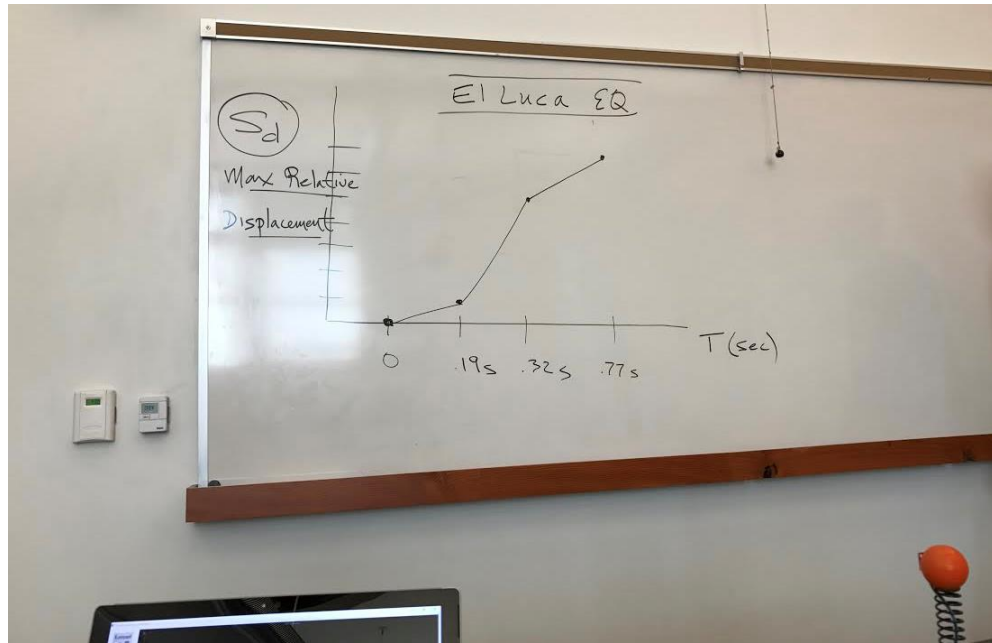


Figure 4.6 Response spectrum created from data taken from the RS DLM in *Seismic Design*

For Instructor B's final demonstration, the different massed RS DLM and shake table were used (Figure 4.7).

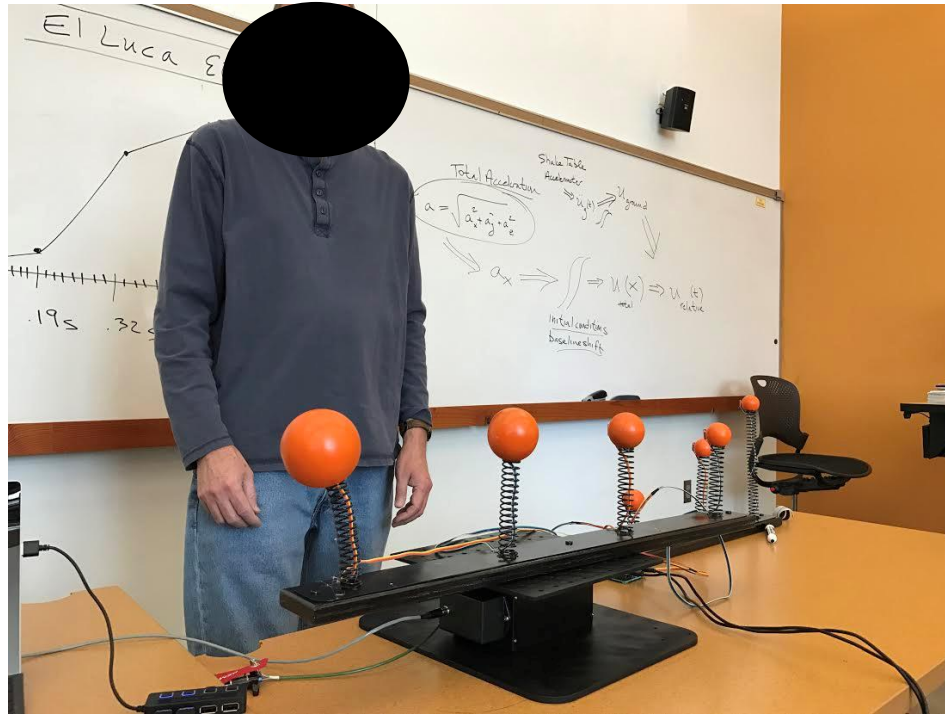


Figure 4.7 Different massed RS DLM in use in *Seismic Design*

Instructor B increased the frequency of the shake table until one of the structures was excited. The heaviest massed structure responded first because it has the longest period. The frequency was increased until each of the structures responded. Through the aid of this demonstration provided by the different massed RS DLM, the students developed the pattern that heavy buildings are going to respond to lower frequencies versus lighter buildings which will respond to higher frequencies.

Natural Periods and the Generation of Response Spectrum Geotechnical Earthquake Engineering Taught by Instructor C

In the *Geotechnical Earthquake Engineering* class, Instructor C used the RS DLMs and instructional shake table to teach the fundamental lesson of seismic sight response and how soils respond during an earthquake. Instructor C first provided the students with the opportunity to observe a

pattern, and by using this pattern to help them develop the supporting theory, promoted inductive learning through the lesson.

Instructor C began the demonstration by using the different stiffness RS DLM and the provided shake table (Figure 4.8).

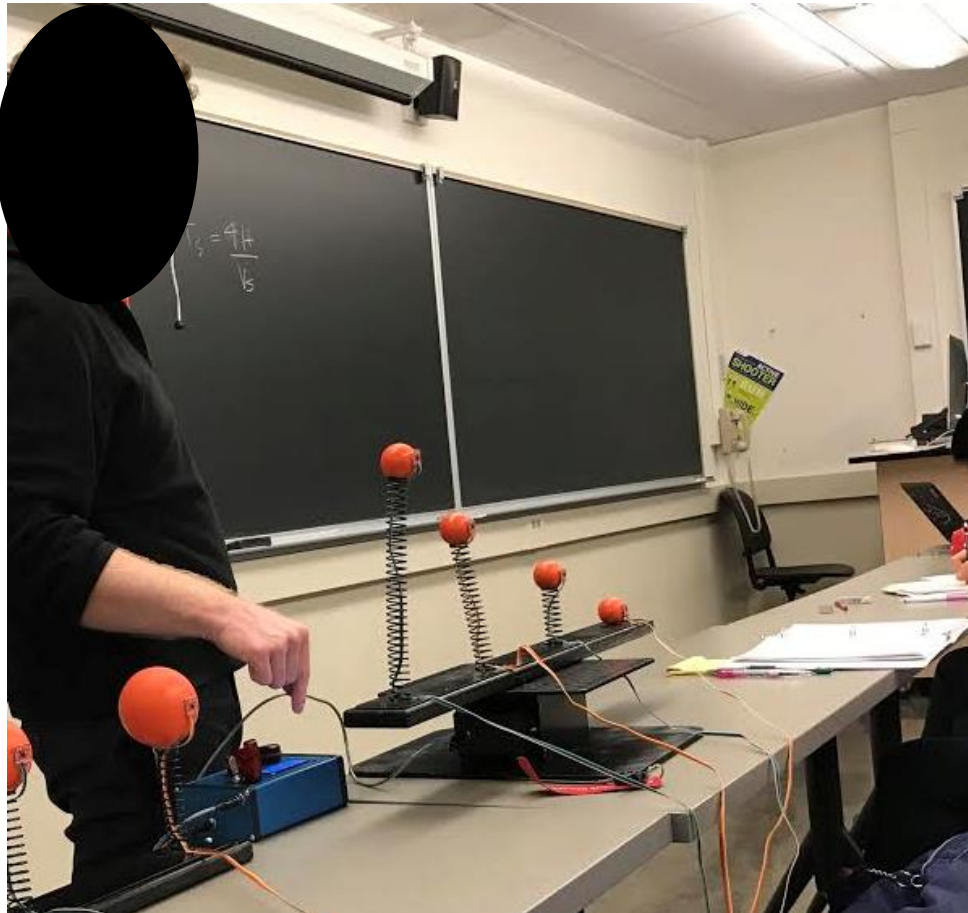


Figure 4.8 Different stiffness RS DLM in use in *Geotechnical Earthquake Engineering*

The frequency of the shake table was increased gradually until the first structure responded. As explained earlier, the least stiff structure responded first because it has the longest period. The frequency of the shake table was increased until each of the sequential structures responded. Students observed that as the stiffness of a structure increases

its natural period increases, and consequently the lower the frequency needs to be for it to respond. By using the demonstration to develop this pattern, the students were using inductive learning facilitated by the RS DLM.

For the second activity, Instructor C used the different massed RS DLM (Figure 4.9) and the shake table. Again, the frequency of the shake table was gradually increased until the heaviest structure responded. The heaviest structure responded first because it has the longest period. The frequency of the shake table was increased until each of the different massed structures responded. The pattern the students developed was that as the mass of a structure increases the period increases and the lower the frequency needs to be for it to respond. For this demonstration, Instructor C used the accelerometer software program to display to the students the high accelerations of the structures as they responded. Furthermore, inductive learning occurred through the development of this similar pattern.

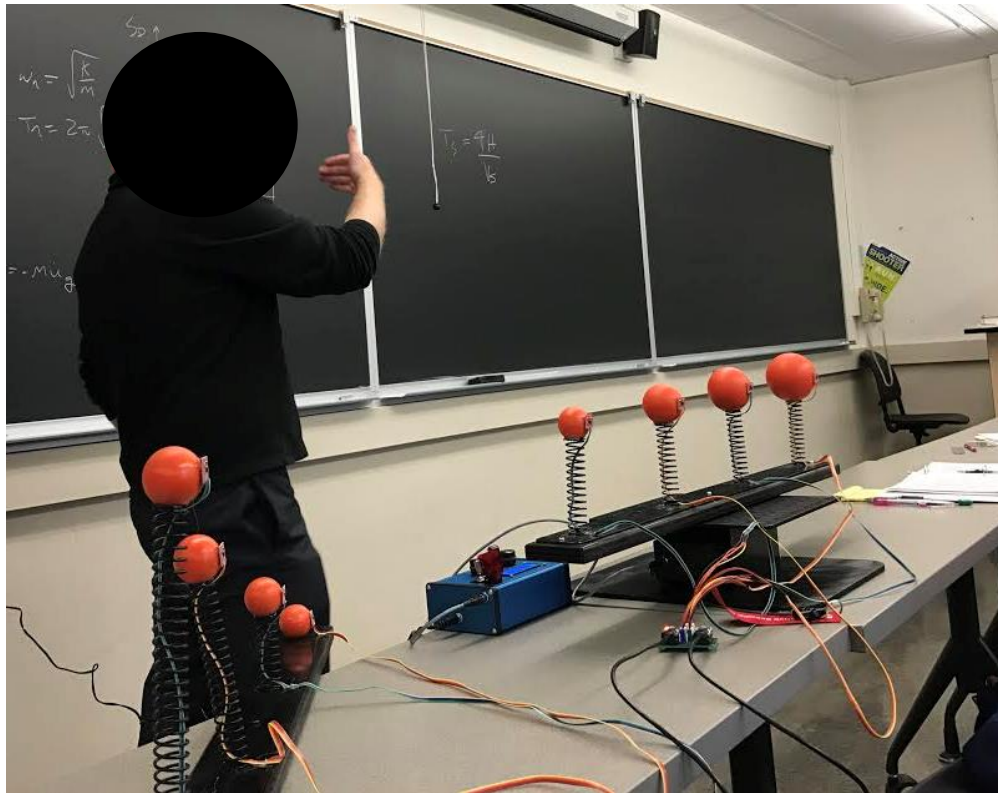


Figure 4.9 Different massed RS DLM in use in *Geotechnical Earthquake Engineering*

To relate back to geotechnical engineering, Instructor C then explained that the analog for the total height of the soil layer is the point mass and the analog for the shear strength is the stiffness of the spring. Therefore, the same pattern and principles apply to the height and shear variables. Instructor C used an inductive learning approach by first demonstrating this phenomenon and then by aiding the students into developing this pattern. Figure 4.10 shows the calculations used to compare the analogs of height and mass and shear and stiffness.

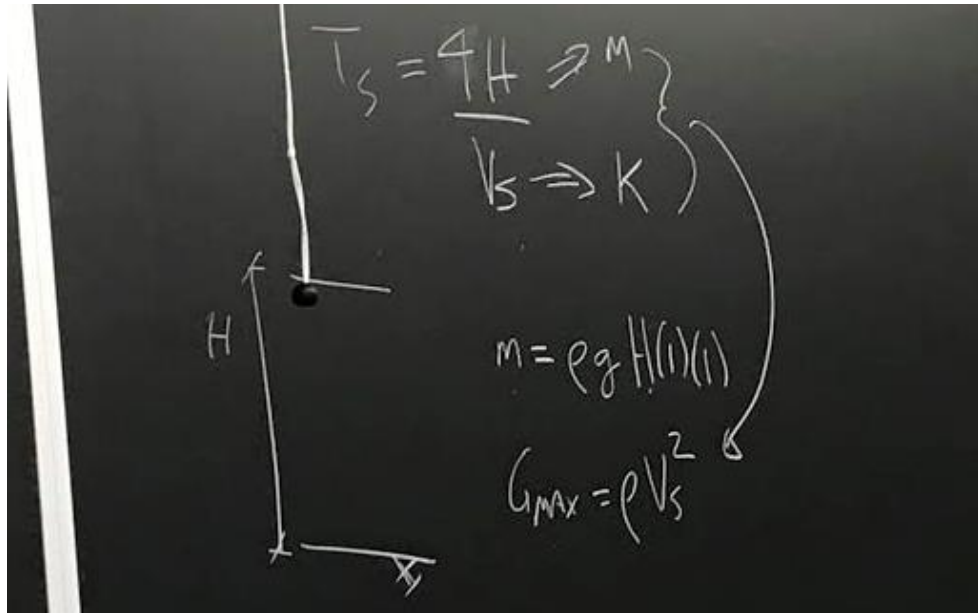


Figure 4.10 Natural period equation related to shear and height in *Geotechnical Earthquake Engineering*

Table 4.1 summarizes the findings for whether or not inductive or deductive learning was promoted through the use of the RS DLM in the three classrooms.

Table 4.1 Summary of the elements observed for the promotion of inductive learning

Lesson Plan Elements Observed	Instructor			Learning Style Promoted	
	A	B	C	Inductive	Deductive
Student operated RS DLM to induce a response in each sequential mass and stiffness	✓	✓		✓	
Students hypothesized the reaction of the RS DLMs before the activity was conducted	✓	✓		✓	
Students were able to visualize a pattern to aid them in developing the theory behind a Response Spectrum	✓	✓	✓	✓	
Background information on the topic was provided		✓	✓		✓
The software program was utilized and student volunteers estimated the results		✓	✓	✓	

Active or Passive Learning?

As explained previously, active learning is defined as, “active, problem-based learning, which poses generative open-ended questions in an environment where students actively participate in their own learning processes” (Kyte et al. 2010). Active learning is one of the many tools instructors use to promote a better understanding of concepts for their students. Evidence suggests that engaging students in the learning process during a presentation – that is, motivating the students to be interactive learners – is an effective method for changing their conceptual understanding (e.g., Hake 2002; Prince 2004; Chi 2009). Based on the definition for active learning, *RQ3* was address through the interpretation of data collected during in-class observations.

Natural Periods and the Generation of Response Spectrum in Design of Steel Structures Taught by Instructor A

In the *Design of Steel Structures* class, instructor A used the RS DLMs and provided instructional shake table to teach the fundamental lesson of earthquake loads and demands and the natural period of a structure. Active learning was promoted through the discussions created by the RS DLMs as the demonstrations progressed.

To keep the students engaged and promote active learning, Instructor A used two student volunteers to operate the shake table. Before the first demonstration with the different stiffness RS DLM, Instructor A asked the class, “Which one is going to respond first?” The majority of the students answered in various ways and then awaited the activity. There was no clear consensus provided by the students of which structure was going to respond first. Instructor A engaged the students before the demonstration to promote active learning. Once the demonstration was complete, students were able to answer the original question based on the pattern and knowledge the demonstration helped them to develop.

Instructor A used a similar line of questioning before the different massed RS DLM demonstration. Instructor A asked, “What do think will happen [this time]?” before the new student volunteer began operating the shake table. Once more, the class was re-engaged before the demonstration occurred by responding with their hypothesis on what was going to happen. Again, the majority of the students participated in providing their predictions. Following, the demonstration, again the majority students were able to answer the question based on the pattern and knowledge they developed through the use of the RS DLM. The students had reached the same consensus. Active learning continued to be promoted.

An activity Instructor A demonstrated before using the provided RS DLMs, involved using their own simulated structure Physical Model with the instructional shake table (Figure 4.11).



Figure 4.11 Alternative physical model in *Design of Steel Structures*

Before the student volunteer began operating the shake table, Instructor A asked the class, “How is the stiffness [of each structure] going to change things and affect the fundamental period? [Which] building is going to respond sooner?” Approximately half of the class responded with various answers and then the activity began. By asking these questions, Instructor A engaged the class and allowed them to begin critically thinking before

the demonstration began. Again, once the pattern was developed through the demonstration, the students were able to answer the question posed to them.

When asked in the post-interview why Instructor A thought the RS DLM was an effective tool, Instructor A answered, “It was effective because it really clearly delineated changes in stiffness and changes in mass and then how those will affect how a structure will respond to earthquakes of different frequencies... I think the in person and hands on really helps to drive the concepts home... I think it was very memorable and I think the students had fun with it so I think it was very effective in really getting the concepts across.” Instructor A was convinced that the hands-on aspect of the RS DLM, one aspect of active learning, aided the students’ comprehension of the class content.

*Natural Periods and the Generation of Response Spectrum in Seismic Design
Taught by Instructor B*

In the *Seismic Design* class, Instructor B used the RS DLMs and instructional shake table to teach the fundamental lesson of generating response spectrums using a single degree of freedom system. Active learning was promoted through the discussions around the use of the RS DLMs.

Before explaining the background of the relevant equations, Instructor B engaged the students by first asking them about the different massed RS DLM asking, “Which spring is going to respond first?” The entire class responded with various answers and Instructor B continued with the equation based background information.

When describing the background on the different stiffness RS DLM, Instructor B asked the class, “Which is most flexible or stiff?” and “Which one is going to have the longer period?” After the majority of the class responded, Instructor B further explained the equations and then proceeded to run the activity using the different stiffness RS DLM.

With the background questions in mind, Instructor B used two student volunteers to run the shake table to continue to promote active learning. As the demonstration progressed, Instructor B had three new student volunteers come up to estimate the periods and frequencies for each structure. Once the demonstration was complete, to run the calculations for finding a calculated period, the instructor and students engaged in discussions on how to use the data they collected to solve for the needed variable. To create the response spectrum, Instructor B used three different student volunteers to estimate the maximum displacement while another student simulated an earthquake with the different stiffness RS DLM. The students created their own outcomes and therefore, were able to develop an understanding of real world concepts through their repeated interactions with the RS DLM. Therefore, the RS DLM promoted active learning throughout this class.

When asked in the post-interview based on Instructor B’s experience, whether they thought the RS DLM was an effective learning tool, and in what ways they found it effective, Instructor B answered, “that it [was] a visual... and physical demonstration of the idea”. They felt that the RS DLM was effective based on it being visual and hands on. Therefore, based on the post-interview, Instructor B believes active learning was promoted through visual and hands on activities.

Natural Periods and the Generation of Response Spectrum in Geotechnical Earthquake Engineering Taught by Instructor C

Active learning was promoted in this class through the discussions facilitated by the instructor and the use of the RS DLMs. However, Instructor C did not use student volunteers to operate the shake table.

Throughout both demonstrations of the RS DLMs, discussion occurred on how each structure was going to react. The majority of this class already understood the principles behind the natural period of a structure therefore, more discussion occurred defining how mass and stiffness are related back to the variables height and shear.

When asked in the post-interview based on Instructor C's experience, whether they thought the RS DLM was an effective learning tool, Instructor C answered, " Yes, I think so. I could tell that the students were much more engaged then they would have been if I was only writing equations on the board nonstop." By engaging the students, the RS DLM aided in promoting active learning.

Table 4.2 summarizes the findings for whether or not active or passive learning was promoted through the use of the RS DLM in the three classrooms.

Table 4.2 Summary of the elements observed to promoted active learning

Lesson Plan Elements Observed	Instructor			Student Engagement	
	A	B	C	Active	Passive
Student operated the RS DLM	✓	✓		✓	
Students asked/ answered questions about the RS DLM	✓	✓	✓	✓	
Students participated in a think/ pair/ share to predict the RS DLM behavior	✓	✓	✓	✓	
Discussion was promoted following the demonstrations	✓	✓	✓	✓	
Instructors found the students more actively engaged with the use of the RS DLM compared to previously taught lessons on similar content space	✓	✓	✓	✓	

Implementation of RS DLMs Across Content Spaces

After implementing RS DLMs into the three classes, post-interviews were conducted to determine the likelihood of an instructor using the RS DLM or an alternative DLM in the future. To further demonstrate the benefits of incorporating RS DLMs into engineering classrooms, the lesson plans with and without the RS DLM were compared to analyze RQ4. This post-interview protocol was specifically designed to address RQ5.

Natural Periods and the Generation of Response Spectrum in Design of Steel Structures Taught by Instructor A

When Instructor A conducted this lesson in the past, they used their own Physical Model as displayed in Figure 4.13. Instructor A incorporated the RS DLM into their lecture by using it right after their own Physical model demonstration. Therefore, the RS DLM was used to add further explanation and aid the students in further developing an understanding

of the natural period pattern in a structure to a previously demonstrated physical model.

When asked why they agreed to use the RS DLM in their class, Instructor A responded, "Because I thought it would be a good supplement to what I was already doing for that particular demonstration. I thought that it would be easier to see the points that I was trying to make about different stiffnesses and different masses and how that effects the response to the ground shaking and I think it worked. I think my little building works but then they have to kind of imagine a little bit more. Whereas, it is a very clear kind of lollipop, single degree of freedom and very easy to see. So I was excited to have like a good supplement to better show the distinction between like changes in stiffness and changes in mass." Compared to their previous lectures on this topic, the RS DLM was able to aid Instructor A more clearly explain the concepts behind this topic.

When asked if the use of the RS DLM in their class changed the way they think about preparing or executing a class, Instructor A answered, "I think it mostly supplemented what I like to do in the class which is have as many hands on demonstrations as possible... I guess just the use of the shake table with it has me thinking more about, 'should I bring in more things where we're actually using a shake table or actually using a physical machine to compress a steel column or something like that?' Those are things I have always wanted to do I just haven't figured out how to do so if had more desktop type loading things that we can bring in to the classroom rather than trying to drag students over to a lab or something then I think that would be great. It does have me thinking a little bit about... other things like that that we can build to supplement

what we have.” Instructor A confirmed that they would use the RS DLM and alternative DLMs in a similar way in the future.

Instructor A also added for possible DLMs in the future, “I already try to have as many hands on as possible but it is usually things we push and pull on and so I think I might think about having other things like the shake table with these types of models where we have a machine or something that is actually pushing and pulling.”

*Natural Periods and the Generation of Response Spectrum in Seismic Design
Taught by Instructor B*

When Instructor B taught this course in the past, they only used equations and white board drawings to teach about these topics. Instructor B incorporated the RS DLMs by briefly providing background equations and information on the topic and then by using the RS DLM to visualize and produce data throughout their journey to creating the response spectrum.

When asked what they thought was interesting about the RS DLM, Instructor B answered, “Because conceptually it can be used to teach the idea of response spectra and that’s really important in a seismic design class I think.” They liked that the RS DLM was a visual and physical demonstration of the topics being covered. The RS DLM added the hands on and physical demonstration to their lesson plan.

When asked if they would use the RS DLM or alternative DLMs in the future, Instructor B answered yes to both and they would use the RS DLM in the same class next year.

Natural Periods and the Generation of Response Spectrum in Geotechnical Earthquake Engineering Taught by Instructor C

Instructor C has typically run this lecture with no visual displays and has relied heavily on teaching the equations and using white board drawings. Instructor C stated they incorporated the RS DLM to, “primarily to describe the physical phenomenon that occurs and then set that up to be able to describe the theory behind why we observe these physical phenomena.” They agreed to use the RS DLM because they believed, “it would increase the learning outcomes for the students.”

When asked what they thought was interesting about the RS DLM, Instructor C answered, “Multiple things, but I guess the most interesting part was being able to tie together geotechnical engineering and structural engineering and the importance of earthquake engineering. It is extremely important that those two fields be linked together. I think that is probably the most interesting.” Through use of the RS DLM, Instructor C was able to demonstrate this phenomenon versus just display the equations.

When asked if they would use the RS DLM again, Instructor C responded, “Yes... I would try to use it multiple ways so I would use it for multiple classes and each class would have a different way.” Instructor C also confirmed they would use alternative DLMs in the future.

Table 4.3 summarizes the findings for implementing the RS DLM across content space and the post-interviews conducted with the three instructors who participated in this study.

Table 4.3 Summary of the observations and post-interviews for the RS DLM across content space

Post-Implementation Interview Questions	Instructor		
	A	B	C
Was the different stiffness RS DLM an effective learning tool?	✓	✓	✓
Would use the different stiffness RS DLM again?	✓	✓	✓
Was the different mass RS DLM an effective learning tool?	✓	✓	✓
Would use the different mass RS DLM again?	✓	✓	✓
Would you use an alternative DLM?	✓	✓	✓

CHAPTER 5 – CONCLUSIONS

Based on the literature review related to the effectiveness of DLMS, the classroom observations, and instructor feedback, it was concluded that the RS DLMs were successful in promoting inductive and active learning. The RS DLM was utilized by three different instructors in three classes: *Design of Steel Structures*, *Seismic Design*, and *Geotechnical Earthquake Engineering*. Following the classroom observations, a post-interview was conducted with each of the instructors. During the post-interviews, all three concluded that they would use the RS DLMs in the future in a similar manner. Furthermore, all three confirmed that they would be willing to use alternative DLMs as well. Five research questions were developed to analyze the effectiveness of the RS DLMs. The research question findings are summarized in the following subsections.

Research Question 1 (RQ1): Can the response spectrum DLM promote inductive learning in the classroom?

This research question was established to guide the assessment of inductive learning through the implementation of the RS DLM in the classroom. In an engineering classroom, inductive learning begins by engaging students with specific examples or activities and providing students with the opportunity to observe and interpret the resulting patterns; thereby, students can construct generalizable understanding (e.g., Felder and Silverman 1988). Through this definition of inductive learning and the classroom observations conducted, all three classes were successful in promoting inductive learning in the classroom.

Through Instructor A's demonstrations, inductive learning was promoted through the use of the RS DLM. Instructor A used an inductive learning

approach by using a demonstration and then allowing the students to use the demonstration to develop a pattern to solve the questions presented to them. The students were engaged by the specific example and used the demonstration to discover a pattern that ultimately lead them to develop the theory behind the natural period of structures.

Instructor B gave similar demonstrations of the RS DLM. However, he used the RS DLM as steps throughout their process of creating a response spectrum. Instructor B began by giving examples of the equations the class was going to analyze and then used the RS DLM to support those equations and give the students a visualization of the theory being studied. The RS DLM promoted inductive learning by again allowing the students to visualize a specific example to develop the theory through the pattern found. Although, by starting with theory in the form of equations, Instructor B also used a deductive approach for a portion of the class period.

Similarly, to the other Instructors, Instructor C also used the RS DLM to demonstrate the theory of response spectra to tie it back to geotechnical engineering, seismic sight response, and how soils respond during an earthquake. The RS DLM promoted inductive learning by providing a specific example to develop the pattern on how soils respond to earthquakes. Once the pattern was developed, the structural components of the RS DLM could be compared to the geotechnical principles in question.

In all three classes the RS DLM was used as a specific activity to allow the students to develop a pattern to comprehend the specific concept being analyzed. Therefore, the RS DLM helped to promote inductive learning in the classroom.

Research Question 2 (RQ2): Did the instructor use an inductive or deductive teaching approach with the response spectrum DLM?

Based on the classroom observations, it was seen that Instructor A, B, and C predominately conducted their interactions with the RS DLM in an inductive manner, although Instructor B, did initially default to a deductive approach initially. The follow-up interviews uncovered that Instructor C would normally teach this content in a deductive fashion, and that the introduction of the RS DLM added an inductive focus to the class. As such not only did the Instructors default to an inductive approach with the RS DLM, it even shifted a standard classroom procedure away from a deductive delivery.

Research Question 3 (RQ3): Did the Response Spectrum DLM promote active learning within the classroom?

Active learning is defined as, “active, problem-based learning, which poses generative open-ended questions in an environment where students actively participate in their own learning processes” (Kyte et al. 2010). Active learning is one of the many tools instructors use to promote a better understanding of concepts for their students. Evidence suggests that engaging students in the learning process during a presentation is an effective method for changing their conceptual understanding (e.g., Hake 2002; Prince 2004; Chi 2009). Based on the definition of active learning and through the use of the RS DLM in each classroom, active learning was promoted.

Through the use of the RS DLM, Instructor A promoted active learning by engaging students before the demonstration began. Instructor A used student volunteers to operate the shake table in to allow the students to

reach their own outcomes through their own actions. Discussions were facilitated by the instructor throughout the RS DLM demonstration. By asking questions before the demonstration, Instructor A engaged the students. Through the demonstration of the RS DLM, the students were able to visualize and utilize the RS DLM and shake table to actively answer those questions. In the post-interview, Instructor A confirmed that the RS DLM was effective in engaging the students versus the lesson without the use of the RS DLM. Therefore, the RS DLM was able to promote active learning in the *Design of Steel Structures*.

Instructor B followed a similar pattern of promoting active learning through the use of the RS DLM by student volunteers and promoting discussion throughout the entirety of the demonstration. Instructor B began by discussing the equations being analyzed and used the RS DLM as a stepping tool to reach the outcome of creating a response spectrum. Several student volunteers were used to operate the shake table, visualize the accelerometer software results, simulate a random earthquake, and estimate several values including the maximum displacement and the period of each structure. The whole class was engaged in discussion throughout the whole demonstration. The class was actively involved in their own learning process. Therefore, through the use of the RS DLM, active learning was promoted in the *Seismic Design* class.

Instructor C also promoted discussion through the demonstration of the RS DLM. However, Instructor C did not use student volunteers throughout the activity. Throughout both demonstrations of the RS DLMs provided, discussion occurred on how each structure was going to react. The majority of this class already understood the principles behind the natural period of a structure therefore, more discussion occurred when

mass and stiffness were related back to height and shear. The RS DLM provided the demonstration that promoted the discussion on geotechnical engineering concepts. Therefore, the RS DLM promoted active learning. Furthermore, during the post-interview, Instructor C confirmed that the RS DLM promoted active learning by engaging the students more than if the instructor had just written on the board. Therefore, through the use of the RS DLM, active learning was promoted in the *Geotechnical Earthquake Engineering* class.

Research Question 4 (RQ4): How did instructors choose to integrate the DLM in their classroom, and how did this integration vary from the originally conceived lesson plan?

Instructor A already used their own physical model in classes in the past. However, by implementing the RS DLM, Instructor A believed that the concepts they were trying to cover were easier to pinpoint and comprehend. Instructor A began with using their own physical model followed by the RS DLMs. The RS DLMs were able to highlight the points Instructor A was trying to make through the use of their original Physical Model. The RS DLM was able to breakdown the pieces of Instructor A's original DLM and help the students further visualize the concepts being covered.

Instructor B used the RS DLM to allow their students to visualize the theory that would typically be written on the board. Without the RS DLM, Instructor B would normally just provide in depth descriptions of the equations documented on the whiteboard by hand. Instructor B incorporated the RS DLM and shake table as scaffolding to add visualization to the original lesson plan. The RS DLM increased student engagement and improve the original lesson plan.

Similarly, to Instructor B, Instructor C generally runs this lesson plan by utilizing a white board and explaining equations without visualizations. Instructor C implemented the RS DLM by adding a visualization to the theory they were already discussing. Instructor C used the RS DLM to describe the physical phenomenon that occurs and then set that up to be able to describe the theory behind what the class observed. Instructor C believed that through the implementation of the RS DLM the class was more engaged and better connections were made between the topics being covered.

Research Question 5 (RQ5): What is the likelihood of an instructor adopting the Response Spectrum DLM or an alternative DLM in future iterations of this lesson or class?

In the post-interview, all three instructors confirmed that they would use the RS DLM in similar fashion again. All three instructors confirmed that they will use the RS DLM the next time they run the similar lesson. Furthermore, all three instructors confirmed that they would use an alternative DLM in the future if it relates to the lessons they are teaching.

Summary of Conclusions

Based on the in-class observations and post-interviews conducted with the participating instructors, both inductive and active learning were primarily promoted through the utilization of the RS DLM. Throughout the class observations both inductive and deductive learning styles were used. However, when the RS DLM was being used, inductive learning was promoted. Discussions were promoted before and after the activities which aided in promoting active learning. Furthermore, following the

post-interview, all three instructors agreed to future use of the RS DLM again in similar lesson plans.

Recommendations for Future Research Needs

Even though the RS DLMs were demonstrated to be highly effective, there are numerous improvements that could be undertaken. In addition to the current collection of RS DLMs, future models could be developed to demonstrate phenomena such as sedimentation, volumetric changes in soil, and soil to structural and transportation system interactions during liquefaction.

There is an opportunity for future research to advance the DLM for future use in future classrooms. These recommendations for future research needs include, but are not limited to, the following:

- Further develop the accelerometer software program to have the following capabilities: determine longitudinal displacements of the masses from the accelerations, determine the relative displacement of the masses with respect to the shake table, determine the maximum displacements, determine the spectral displacement, determine the pseudo-acceleration, and easily display the natural period, natural frequency, and natural circular frequency.
- Not all classrooms were compatible with linking the software program to a projector. Therefore, better preparation and instrumentation may be necessary.
- Instrument the shake table with an accelerometer.
- Program the shake table to simulate an actual earthquake ground motion.

- The RS DLMs need a clasping device to tie them to the shake table to prevent them from sliding off.
- A longer class period may be necessary to fully reach the potential of the RS DLM
- The creation of alternative DLMs to relate to other engineering areas of focus. For example, a DLM with the capabilities of pushing and pulling.

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APPENDICIES

APPENDIX A

CLASSROOM OBSERVATIONS

Instructor A – Design of Steel Structures

1. What class is this?
 - a. Number – CE 383
 - b. Title – *Design of Steel Structures*
 - c. Graduate / Undergraduate - *Undergraduate*
 - d. Elective or required - *required*
2. How many students are in the class? - 45 - 50
 - a. Distribution of Graduate / Undergraduate - *Undergraduate*
3. Are both models being used? - YES
4. Is the instrumentation package being used? - NO
5. Is the shake table being used? - YES
6. Is the computer program being utilized? - NO
7. Are other tools being used? - YES
 - a. What are they? – *simulated structures with play-doh.*
 - b. How are they being used? – *simulated earthquake to demonstrate the concept of natural period with different heights and then different masses.*
8. Is the instructor using the model alone or are students using the model? – *student volunteers; guided by instructor*
9. Is the activity being used or did the instructor provide their own activity? – *Instructor provided activity*
10. What fundamental lesson is being taught? – *Earthquake loads/demands. Natural period of a structure (also demonstrated and went over equation).*

Activity 1: Structure with no mass was used first. The student volunteer increased the frequency slowly. This demonstrated that the taller building would react first. Professor then added mass to the structure on both models. She asked, “How is the stiffness going to change things and affect the fundamental period?” The answer was a longer period. She then asked, “Is the building going to respond sooner?” The answer was yes. After the taller building responded first, they waited and increased the frequency until the shorter one began to respond.

Activity 2: Started with different masses DLM and the student volunteer increased frequency slowly. Professor asked, “What do you think will happen?” The answer was the higher frequencies lead to the lower massed objects responding and vice versa.

Activity 3: The DLM with different stiffness was used. The professor asked, “Which one is going to respond first?” The answer was the most

flexible (tallest) object because it has the longest period. The student then increased the frequency slowly until each of the other springs responded. The activities focused on the fundamentals of frequencies. The follow up to these activities was an Earthquakes Lab. (See slides)

11. What questions are students asking? – conceptual questions around the equations
12. What questions did the instructor ask of the students? – Which structure is stiffer? Which structure has the longer period? Which structure do you think will respond first?
13. What issues if any occurred? - NONE
14. Possible improvements to the specific class.
15. Notes
16. Pictures

Instructor B – Seismic Design

1. What class is this?
 - a. Number – CE 589
 - b. Title – *Seismic Design*
 - c. Graduate / Undergraduate - *Graduate*
 - d. Elective or required – *Elective*
2. How many students are in the class? - 15
 - a. Distribution of Graduate / Undergraduate - *Graduate*
3. Are both models being used? - YES
4. Is the instrumentation package being used? - YES
5. Is the shake table being used? - YES
6. Is the computer program being utilized? - YES
7. Are other tools being used? -NO
 - a. What are they? - NA
 - b. How are they being used? - NA
8. Is the instructor using the model alone or are students using the model? – *Instructor along with student volunteers.*
9. Is the activity being used or did the instructor provide their own activity? – *Instructor provided own activity.*
10. What fundamental lesson is being taught? – *DLM used to generate a response spectrum using a single degree of freedom system.*

Background 1: Different Mass DLM addressed first: Instructor asked “Which spring is going to respond first?” – class said both. Started with explaining the equation of frequency ($f = 1/T$). Instructor asked “If mass goes up what does that do to omega ($\omega = 2\pi f$)?” – Omega goes down which means that f (frequency) goes down and T (period) goes up.

Background 2: Different Stiffness DLM addressed second – Instructor asked “Which is most flexible/stiff?” The answer was the tallest one. Instructor asked, “Which one is going to have the longer period?” – the tallest one. The instructor then explained the equation in relation to stiffness – if the stiffness goes up omega goes up, f goes up, and T goes down.

Activity 1: Different stiffness DLM: Instructor asked “What is the estimated period of the different springs?” A student volunteer was selected to estimate the periods for each spring visually using the accelerometer software. The student volunteer then began to increase the frequency of the shake table to get each object to respond. Once the object responded, the shake table was stopped and the frequency was recorded. Using that number(frequency), T (period) was solved for. The same thing was done for the remainder of the objects.

Activity 2: Instructor created a response spectrum on the board. Student volunteer created a simulated earthquake with the DLM to create the response spectrum. There were three observers instructed to watch the three springs. They were instructed to estimate the displacement caused by the earthquake. On the board the instructor plugged in the calculated periods on the graph and then plugged in the estimated displacements. Following the creation of the spectrum, the instructor tried to determine the relative displacement using the acceleration. Equation for acceleration to relative displacement – double integration.

Demonstration 1: Different masses DLM – instructor asked “Which mass is going to respond first?” – the answer was first one (the heaviest mass). The instructor used this DLM as more of a demonstration then a lesson. The take away from this demonstration was that different frequencies effect different buildings differently.

11. What questions are students asking? - NA
12. What questions did the instructor ask of the students? – *Noted above*
13. What issues if any occurred? - *Could not hook up surface to the projector. Cannot change the axis to visualize the period for each spring (worked later but not when necessary).*
14. Possible improvements to the specific class. – *The DLM software only measures acceleration, it cannot measure displacement. Shake table cannot produce a random earthquake. Need to attach DLM to the table in a better way.*
15. Notes
16. Pictures

Instructor C – Geotechnical Earthquake Engineering

1. What class is this?
 - a. Number – CE 578
 - b. Title – Geotechnical Earthquake Engineering
 - c. Graduate / Undergraduate - *Graduate*
 - d. Elective or required - *Required*
2. How many students are in the class?
 - a. Distribution of Graduate / Undergraduate – 9 (2 undergraduates)
3. Are both models being used? - YES
4. Is the instrumentation package being used? - YES
5. Is the shake table being used? -YES
6. Is the computer program being utilized? - YES
7. Are other tools being used?
 - a. What are they? -NO
 - b. How are they being used? -NA
8. Is the instructor using the model alone or are students using the model? – Instructor used models alone.
9. Is the activity being used or did the instructor provide their own activity? – Instructor provided own activity.
10. What fundamental lesson is being taught?
 - a. Instructor began with explaining natural frequency and response spectrum by explaining the equation. Instructor explained that as the stiffness decreases the period decreases. Instructor then explained that as the mass increases the period increases. How the ball is moving relative to the ground (relative displacement).
 - b. Instructor began with demonstrating the different stiffness DLM model. Began gradually increasing frequency of shake table to create a response in the tallest string. Instructor is trying to get each spring to resonate. One over the frequency equals the period. Frequency was increased until each spring responded.
 - c. Instructor demonstrated the different mass DLM. Started with higher frequency and shorter period to make smallest massed spring respond. Decreased frequency to get each spring to respond. Used software program to demonstrate the high accelerations of the springs as they responded. The analog of height is mass and the analog of shear is stiffness.
11. What questions are students asking?

- a. Student asked which DLM relates to H. Instructor answered the different stiffness DLM because H deals with mass and with this model all the masses are the same.
- 12. What questions did the instructor ask of the students?
- 13. What issues if any occurred?
 - a. When DLM reaches high frequency it is hard to keep it on the shake table.
- 14. Possible improvements to the specific class.
 - a. Attaching the DLM to the table
- 15. Notes

APPENDIX B

INTERVIEW PROTOCOL

Concept:	Interview Question:	Probing Questions:
Introduction	<p>Ask how the participant is doing.</p> <p>Introduce myself.</p> <p>State the purpose of the interview: “To review your experiences with the Desktop Learning Modules (DLMs) and to learn about your experience with these DLMs in your classrooms”.</p> <p>We are enthusiastic to know everything about your experience with the DLMs, so if I don’t ask about particular element of your experience that you think maybe of interest to us, please feel free to share those details with us.</p> <p>You can choose not to answer any of the questions and may stop the conversation at any time for any reason.</p> <p>Explain to the participant that their answers are confidential. Ask if it is okay to audio record.</p> <p>Ask participant: “How many years of experience do you have teaching college classes?”</p>	
Participation	Why did you agree to try to use the DLM in your classroom?	<p>What did you think was interesting about the DLM?</p> <p>What did you think might be challenging about using the DLM in your classroom?</p>

Implementation	<p>What topics did you choose to cover while using the DLM?</p> <p>How did you use the models in your class?</p> <p>What class did you use the models in?</p>	<p>Why did you choose this/these topics?</p> <ul style="list-style-type: none"> • Convenience, was it in your plan for the class? • Was it the best match for the DLM that you could envision? <p>Name of Class? Graduate or Undergraduate? Elective or Required? How many students? What type of class would be the best fit for these questions?</p>
Materials	<p>Based on your experience, was the DLM an effective learning tool? In what way was it effective?</p> <p>Did you have any specific uses of the DLM that you liked more than others? Why or why not?</p> <p>Did you have any specific capability of the DLM that you liked less than others? Why or why not?</p>	<p>Why do you think the DLMs were/were not an effective learning tool?</p> <p>Why was this your preferred use of the DLM?</p>
Students' Feedback	<p>What types of feedback or comments did students provide about the models?</p>	<p>Did you have any particular student feedback (negative or positive) which you want to share with us?</p>
Method of Teaching	<p>Did the use of a DLM in class change the way you</p>	<p>If yes: How exactly did you modify your way of</p>

	think about preparing or executing a class?	<p>thinking about teaching? Please be specific to the extent possible.</p> <p>If no: Are you going to change your way of teaching based on using a DLM? (how/why?)</p>
Future Plan	<p>Would you use the DLM again in future?</p> <p>Will you consider designing further lecture materials or activities for students around models like these in the future?</p> <p>Will you introduce these models to your colleagues? If so, how would you introduce that?</p>	<p>If Yes:</p> <ul style="list-style-type: none"> • Why? • How? <p>Would you use them to teach similar content or different content?</p> <p>If No:</p> <ul style="list-style-type: none"> • Why? <p>If Maybe:</p> <ul style="list-style-type: none"> • What might influence your decision? <p>What would you modify about the DLMs?</p>
Conclusion	<p>Are there any other notes that you feel are important and was not covered in our conversation?</p> <p>“Thank you for your time”</p> <p>Stop Recorder</p> <p>State that a follow-up short interview might be necessary.</p> <p>State that participant can email me if he/she has anything else to share.</p>	