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Utilize Project to Help Students Learning in Mechanical Vibration Course

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Abstract

Mechanical Vibration has been a three credit required course by the Mechanical Engineering program at Wentworth Institute of Technology (WIT) since Spring 2014. Many students struggle in this course because of two reasons： 1) the level of math involved; vibration course needs to solve differential equations. While most students took differential equations course in their sophomore year, there is a huge time gap. 2) No lab unit; students have difficulty connecting the motion of the system and equations learned in class. A vibration project was introduced in Spring 2017 to overcome the shortage of labs. The purpose of the project is to demonstrate the principles and multiple computational techniques of real vibrating systems. Students choose one of the two proposed systems: a spring-mass-damper system or a harmonically excited spring-mass system and work in groups (3 members) to build the prototype with a budget of $50. The groups then compare the vibration characteristics of their system to those calculated analytically and computationally. As a result, most groups worked with the first choice – a single degree of freedom free vibration system. Many groups built their system using household items and various interesting forms were designed. The survey showed the project helped students grasp a better understanding of real-life vibrations, which an engineer would have to put time into modeling variations of said systems. One of the student projects was further developed as a demonstration of free and forced vibration in the course. This paper presents the project students designed, the challenges they faced, and the benefits they achieved from this project.

I. Introduction and Background

Engineering is a practicable discipline, a hand-on profession where doing is the key [1]. Project-based learning is a dynamic method to inspire students to obtain a deeper understanding of the subjects, apply and integrate knowledge they are studying. Normally a project is a complex task that involves design thinking, decision making, problem solving, etc. [2]. The benefits of project-based learning include improved student participation in the learning, strengthened communication skills, promotion of critical and proactive thinking [3]. Literature shows that real world problem will improve student's understanding of the materials learned in classroom [1]. Laboratory work motivates students to learn actively, thus it has been widely applied to many engineering subjects [4~9].

Mechanical Vibration Course has been offered starting Spring 2014 for senior BSME students: three credit with lecture only. Many students struggled in this course because of two reasons: 1) The level of math involved. Vibration course requires students to model and solve the system equations which are represented by 2^{nd} order different equations. While most students took differential equations course in their sophomore year, there is a huge time gap; 2) No lab unit. Students had difficulty to connect the motion of the system and equations learned in class. Majority of the students at WIT have the "learn by doing" stereotype and are good at hands-on activities. Most engineering courses at WIT have labs and the contents learned in the lecture are reinforced by hands-on experiments. It is hard for them to understand and grasp the materials for a lecture only course, especially courses like vibration with strong practical applications. Some researchers developed experiments for mechanical vibration course [10~11]. However, these experiments were not implemented in the present course because of the lack of laboratory unit. Instead, simulation was used to show the response of the system in various cases. Students still feel that it is hard to understand.

Furthermore, vibration is an application course that uses many concepts from previous courses. For example, students need to recall the knowledge from Mechanics of Materials course to determine the spring constant of a beam. They need to recall the knowledge from Dynamics course to setup the equation of motion for a system. They also need knowledge from Differential Equation Course to solving 2nd order ordinary differential equations. Therefore, mechanical vibration is a relatively harder course for students.

A project was introduced in Spring 2017 to overcome the shortage of labs and knowledge. Survey showed the project helped students grasp a better understanding of real-life vibrations an engineer would have to put time into modeling variations of said systems. Eighty two percent of the students believe the project helped them understand the course materials better and the majority (91%) of students think the project helped apply the principle taught in the course in a practical way.

The rest of the paper is organized as follows. Section II describes the project, followed by some examples of system students designed in section III. Section IV shows the students' response to our survey. The survey results confirm the project was beneficial to them as it helped them understand the concepts and apply the principles taught in class in a real system. Finally, section V concludes the paper, summarizing our experience and knowledge gained through this project.

II. Project Description

The objective of the project is to connect the principles, analytical and computational techniques learned in lecture to real vibrating systems. To do this, students work in groups to choose one of the systems listed below. There are specific requirements the group must meet for each type of the system.

1) Spring-mass-damper system: must be able to demonstrate underdamped (at least 3 periods of underdamped motion must be observed) and overdamped operation. The vibration characteristics to be analyzed should include k, m, c, damped frequency, and the response to an initial displacement or initial velocity for both the underdamped and overdamped case. Here, k is the spring constant, m is the mass, and c is the damping constant.

2) Harmonically-excited spring-mass (could also have damper) system: must be able to demonstrate harmonic excitation at the resonant frequency, and above and below the resonant frequency of your system. The vibration characteristics to be analyzed should include k, m, natural frequency, and the response to a driving frequency below, at, and above the natural frequency. If damping elements are included, their coefficients should be characterized.

Students are required to work as a group and build the prototype with a budget of $50 dollars and then compare the vibration characteristics of their system with those analytical and computational results. Finally, a report is submitted and a brief presentation is made to the class about the group's findings.

III. Sample Students Work

(1) Characterize the System

Students are asked to determine the mass m, spring constant k, and damping constant c of their systems. The values of m and k can be measured through scale and Hooke's Law or manufacturing sheets. If a beam is used as the spring element, the spring constant k is calculated based on the setting of the beam – cantilever or simple supported beam.

The first challenge that students face was what materials could be used as dampers and how to find the damping constant, since it was not given from the part/material's specification sheets. Students were guided to use the log decrement to calculate the damping ratio ζ and then the damping constant.

Figure 1 shows a typical response for an underdamped system. The damping ratio can be calculated by: $\zeta = \frac{\frac{1}{n-1}\left(ln\frac{x_1}{x_n}\right)}{\sqrt{4\pi^2+\left[\frac{1}{n-1}\left(ln\frac{x_1}{x_n}\right)\right]^2}}$, where x_1 and x_n are the amplitudes at different cycles: 1st and the nth, and then the damping constant is calculated as: $c = 2\sqrt{mk}\zeta$.

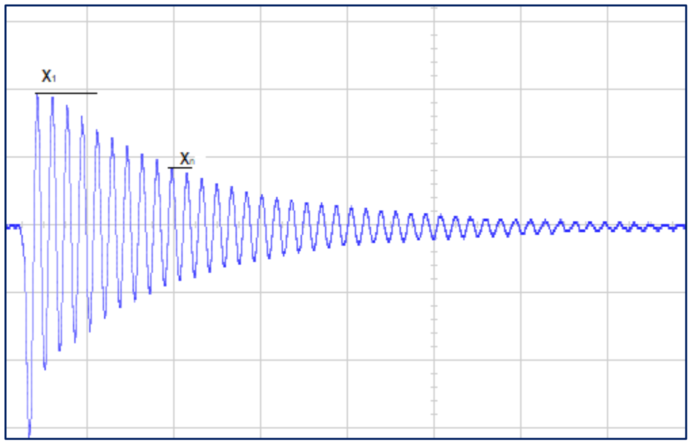

Figure 1. Free vibration response

The next challenge was how to get the response of the system, which was required to calculate log decrement. Most students recorded slow motion videos of the mass and manually measured the maximum displacement of the mass at different cycles. Only a few teams worked with the data acquisition to get relative accurate data. Students were guided to use the built-in accelerometers of their smart phones to record data as well, which is demonstrated as one of the projects listed in next section.

Natural frequency of the system was calculated after obtaining all system parameters. Students also created the simulation model using MATLAB/Simulink or WorkingModel. The results obtained from simulation were then compared with those of hand calculation and experiments. Overall around 10% of errors was obtained in terms of the natural frequency of the system. Some simulation models and results are shown in next section.

(2) Example Systems

Most groups worked with the first choice – a single degree of freedom free vibration system with household items, among which various interesting forms were designed. The following shows some examples:

a. Free vibration: Single Degree of Freedom (SDF) spring-mass-damper system

In this system, student groups chose proper values of mass, spring, and damper to demonstrate underdamped and overdamped situation.

- A system contained a cantilever beam with a strain gauge attached is shown in Figure 2. The group used data acquisition board and LabVIEW to record the displacement of the beam.

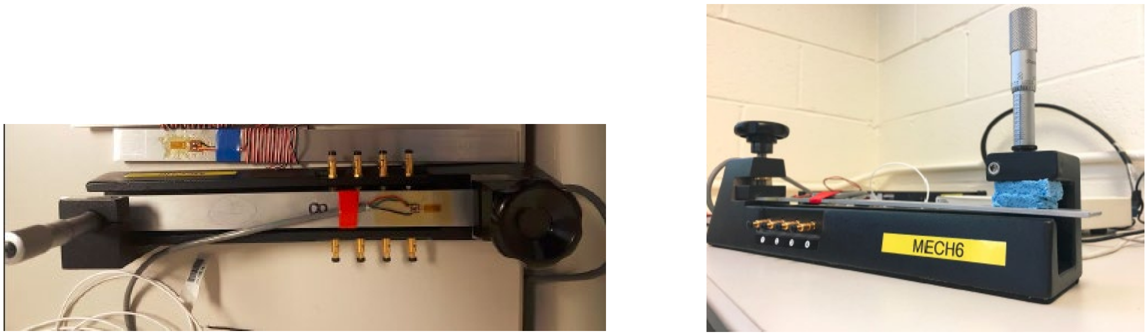

Figure 2. A cantilever beam with strain gauge

- One group built a single degree damped vibration system with a 39-gram hot wheels race car. The car was superglued to a spring with a spring constant 452.77 N/m. Pictures were taken from the slow-motion video of the system. Figure 3 shows the hot wheel car at the peak amplitude. Besides the physical model of the vibration system, students were required to use modern tools to simulate the results. Figure 4 shows the simulation model and results using WorkingModel.

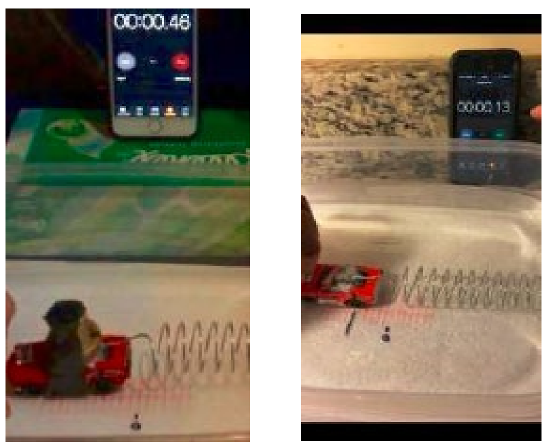

Figure 3. A hot wheel race car model

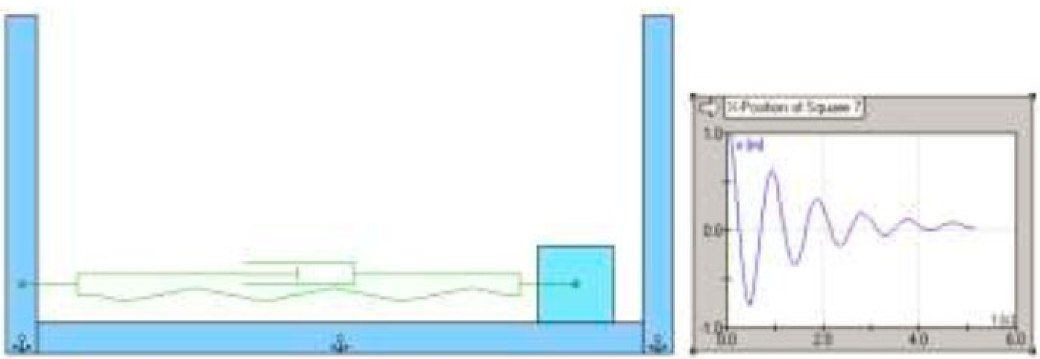

Figure 4. Simulation model and results using WorkingModel

The team also developed a MATLAB graphic user interface to take the input parameter from the user and then simulate the system (Figure 5).

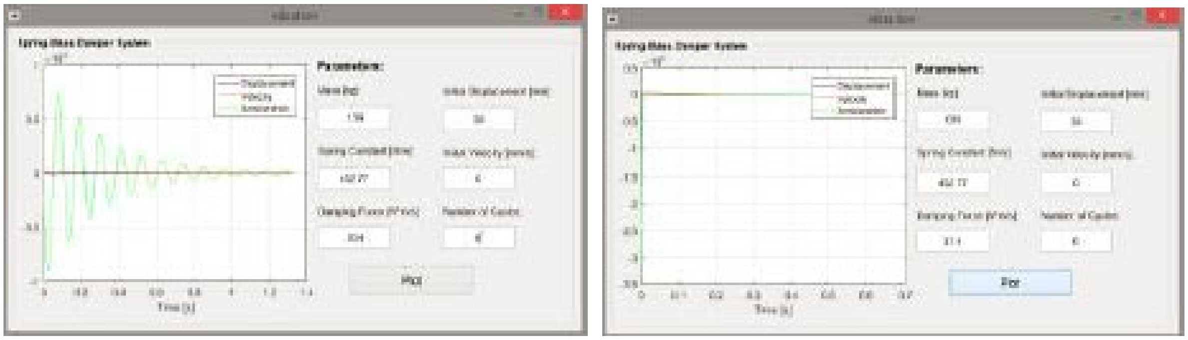

Figure 5. MATLAB GUI for the hot wheel car model

- A system included a smart phone as the mass component and its built-in accelerometer to record the motion of the system, a single tension spring from a spring scale and a rod-flydisc-in-fluid acting as a damper is shown in Figure 6. The system was able to demonstrate under-damped and overdamped vibration with different fluids and test damping effects. The fluids varied from air to water to honey and best results were recorded for each fluid (air being a low viscosity and working to higher viscosity fluid like honey). The results were consistent with the theoretical calculations.

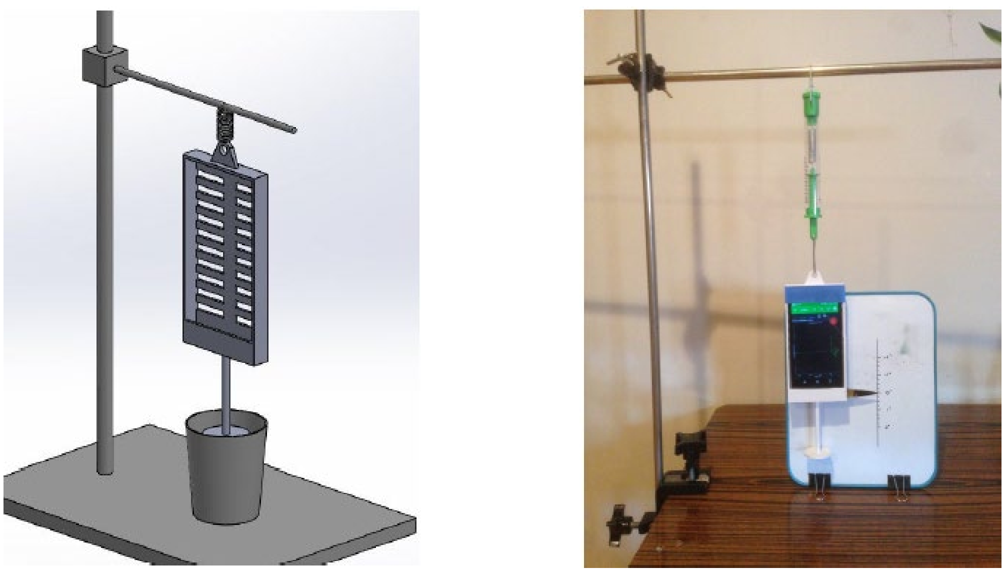

Figure 6. SolidWorks and physical model of a spring-mass-damper system

- Some other forms of simple spring-mass-damper systems are shown in Figure 7.

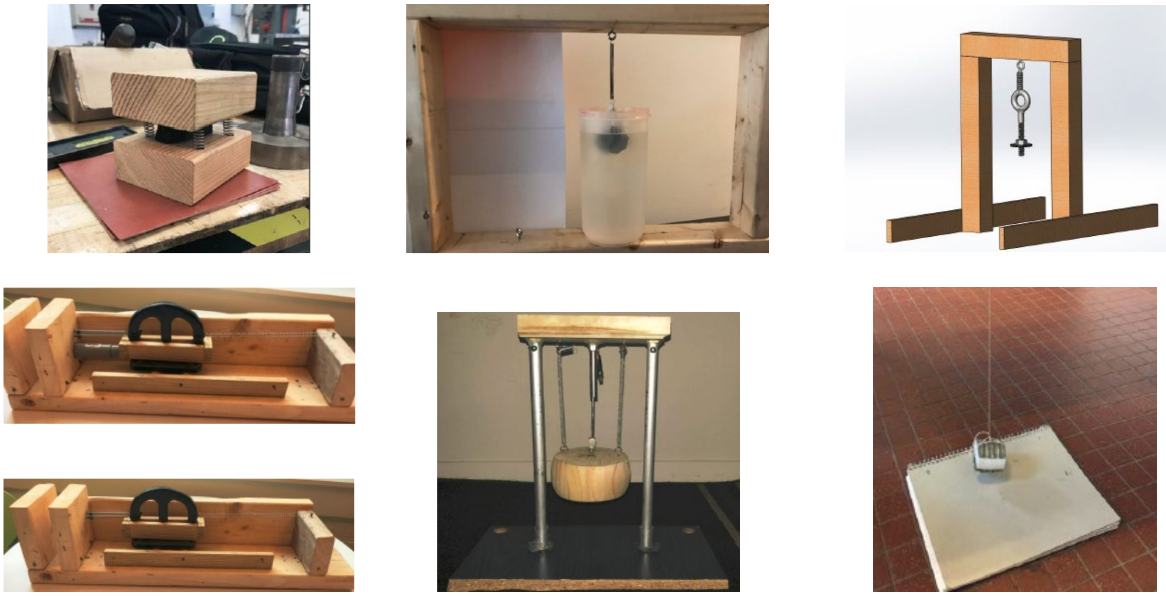

Figure 7. Spring mass damper systems and a pendulum system.

b. Harmonic excited vibration

Several teams worked on harmonic excited vibration systems.

- A team designed and implemented a rotating unbalance system that used a rotor with unbalanced mass attached. The system and its Simulink model are shown in Figure 8 and 9. A 10% error was obtained comparing the calculated natural frequency of the system and the experiment data.

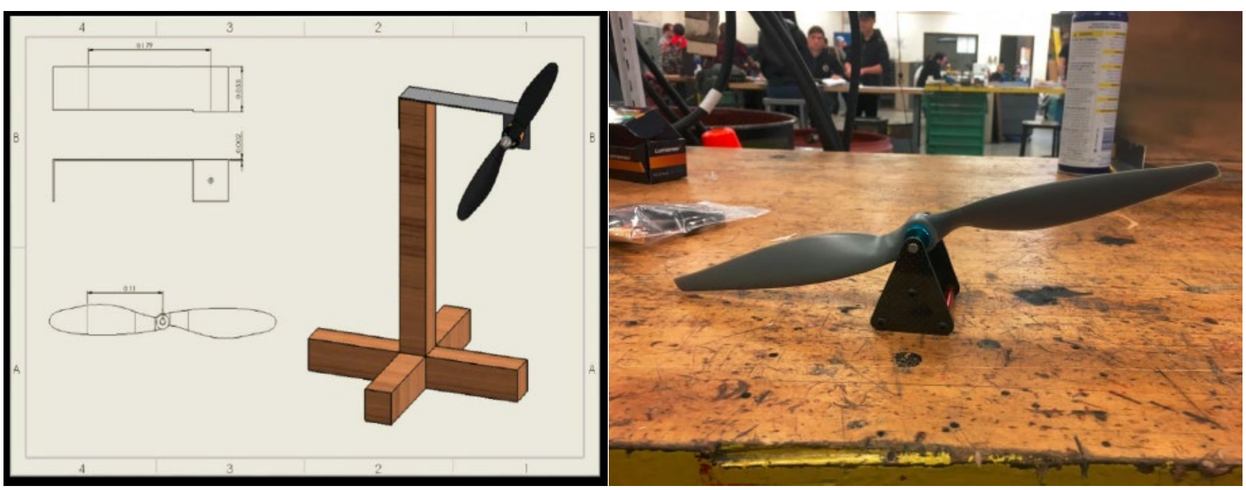

Figure 8. Rotor model

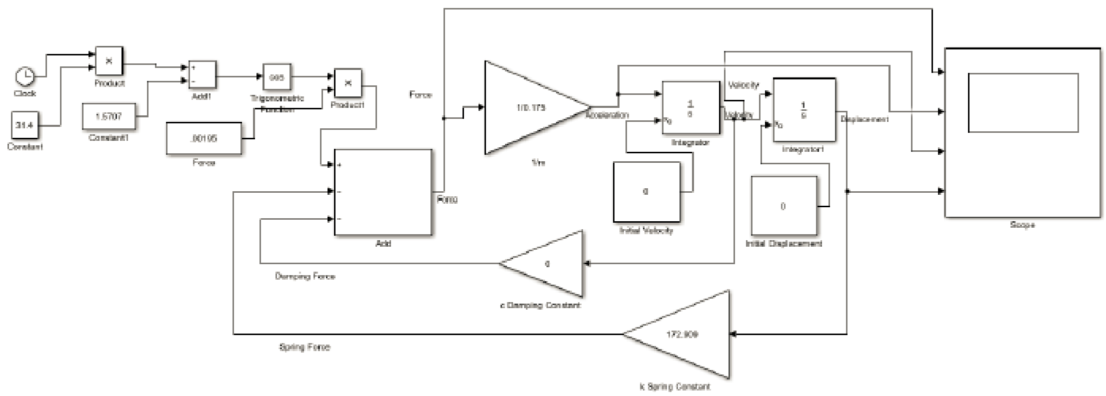

Figure 9. Simulink model for the rotor

- Figure 10 shows a harmonic excited spring-mass system using a solenoid to apply a force with various frequency. An Arduino was used to control the frequency of the solenoid as well as display the reaction of the spring-mass system. When the frequency of the solenoid was set to the resonance frequency found analytically, 3.9, the system oscillated and eventually had such a large and rapid displacement that the mass fell off the system.

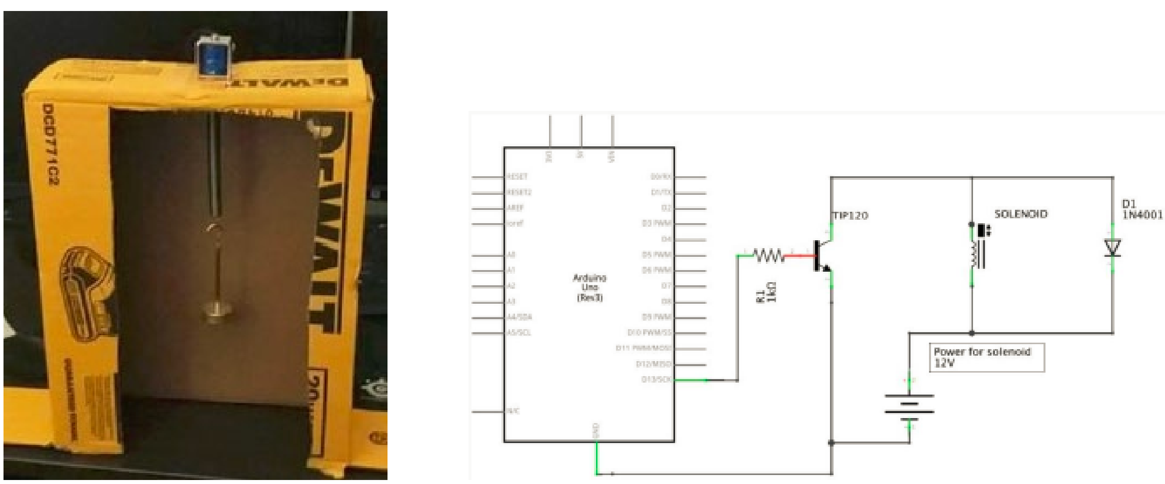

Figure 10. A vibration system excited with harmonic forces

- An example of a beam oscillating caused by rotating unbalance is shown in Figure 11. The system included a beam constructed from a 6061 aluminum bar and a motor with unbalanced mass attached sitting in the middle of the beam. The bar was suspended in the air using a wooden pillar on each end and measured 24 inches in length between the wooden pillars. The motor span and caused the unbalanced mass to spin resulting in oscillations, which then excited the aluminum bar to vibrate up and down as a response to the reciprocating unbalanced mass. The team also designed and built a mechanism to record the motion of the beam on paper.

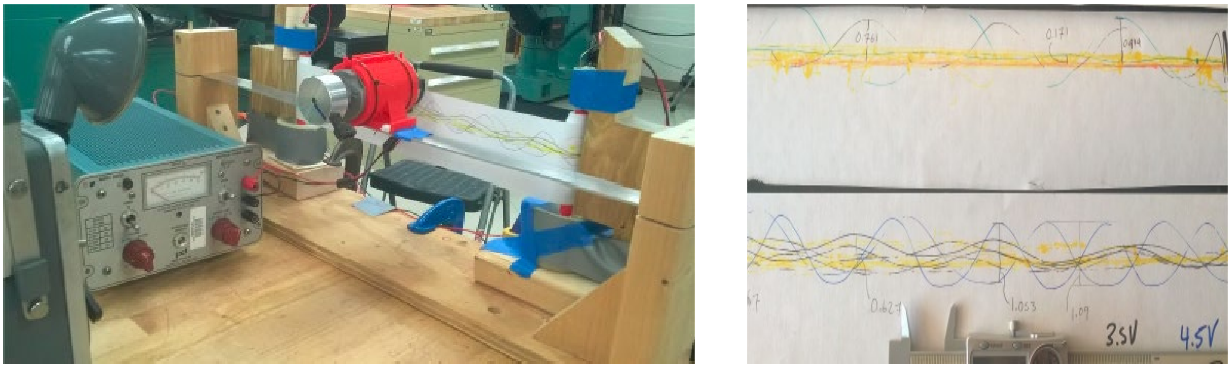

Figure 11. Harmonic excited vibration graphing machine (left) and the graphs drawn by the machine (right)

IV. Survey Results

A survey was conducted after students completed the project and the overall feedback was positive. Figure 12 shows the average scores of the survey questions in a scale of 5: 1- strong disagree, 2 – disagree, 3- neutral, 4 – agree, 5 – Strong agree. The detailed survey results are shown in Figure 13.

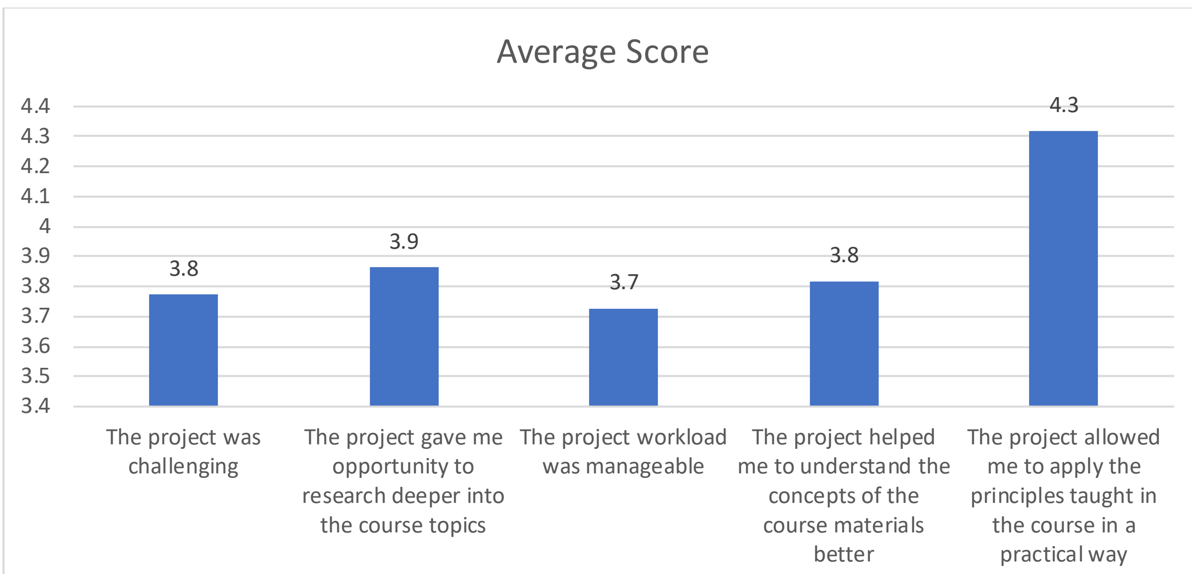

Figure 12. Average score of survey questions

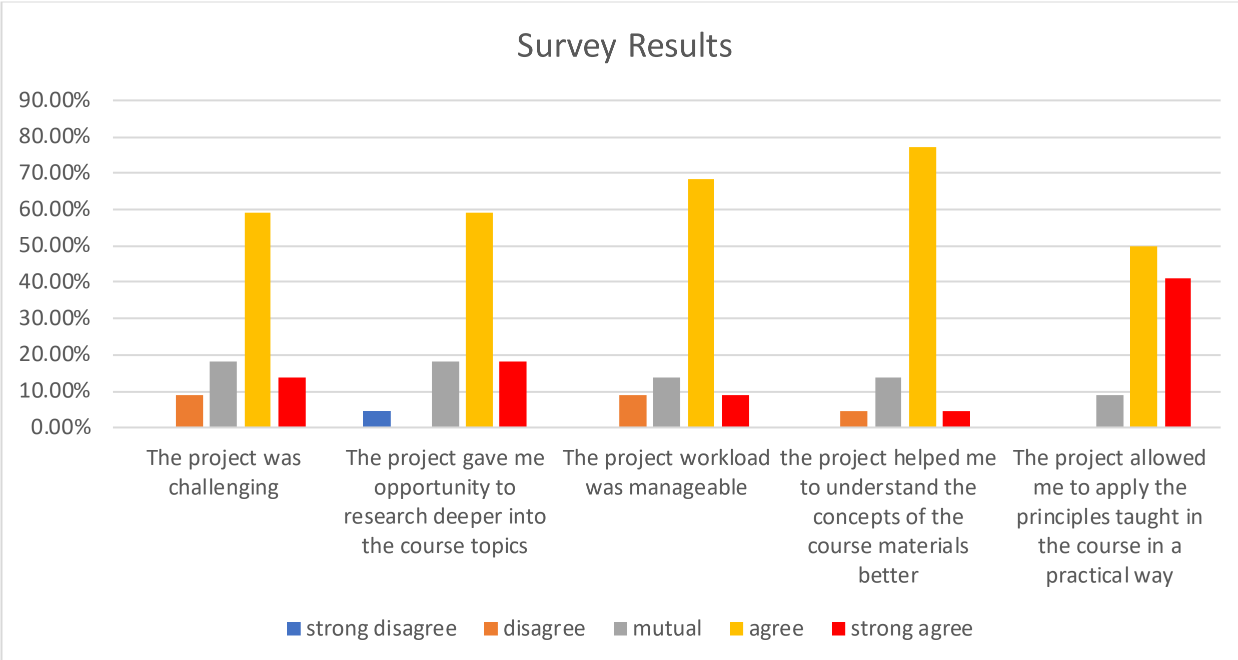

Figure 13. Detailed survey results

Was the project manageable?

Seventy seven percent of the students agreed that the project workload was manageable. The average time spent on this project per student was 11 hours including report writing, which was a reasonable time for a team of 3 students working on a project. 73% of the students thought the project was challenging because it was an open-ended project and no detailed instructions were given to build the system. Some comments stated that "examples of the previous project would be helpful", "More specific guideline would be better".

Seventy seven percent of the students agreed the project gave them the opportunity to research deeper into the course topics. 82% students agreed the project helped them understand the course materials better. And 91% students thought the project allowed them to apply the principles taught in the course in a practical way. The examples showed in the previous section show that students designed all kinds of forms for their spring-mass-damper systems and learned how to characterize the spring constant, damping constant for the system. Students learned that the system would behave differently if the system perimeters change.

Was the project beneficial?

Survey data show that 80% students thought the project was beneficial to them. Some example comments were: "To make your own vibrations system and understand how it works is an extremely valuable experience.", "it taught me there's a lot of things you can use as a damper and not just a physical mechanical model". "it allowed me to actually build a vibrations system instead of just seeing them on paper.", "got experience of turning a learning concept to a physical working model".

Some students (20%) complained that the project added burdens to their already heavy loaded semester: capstone design research and other courses with multiple lengthy reports, as well as part-time jobs. In Spring semester, time was critical since most students put high priority on their capstone design research.

The project was typically assigned 4~5 weeks before the final exam. It could be assigned earlier so that the students would have more time to think and be more prepared.

Overall, survey results show the project was implemented successfully. The objective of the project was met. Students gained lots of hands-on experience about modelling the vibrations from real-world examples. This project connected the principles, and analytical and computational techniques learned in lecture to real vibrating systems.

V. Conclusion

Mechanical Vibration is a strong application-oriented course. While many programs have laboratory experiments that help students understand the material taught in class [10-11], the current course offered does not have lab units because of certain reasons. Most students at WIT have the "learn by doing" stereotype. This increases the difficulty of understanding the materials. A project was implemented to overcome the shortage of lab experiments. The purpose of the project is to demonstrate the principles and multiple computational techniques of real vibrating systems.

The survey results indicated that the project was successfully implemented. Students gained tremendous experience in characterizing vibration systems, and the experiment results were consistent with those of hand calculation and simulation. Seventy seven percent of the students think the project was manageable although time was a big concern for certain students due to the heavy workload in Spring semester of senior year. Eighty percent of the students think the project was beneficial to them. Eighty two percent of the students believe the project helped them to understand the concepts of the course materials better. Ninety one percent of the students think the project allowed them to apply the principle taught in the course in a practical way. The beam vibration project shown in Figure 2 is further developed to demonstrate the underdamped and overdamped and harmonic excited vibration in class.

Reference:

[1] Feisel, Lyle D., and Albert J. Rosa. "The role of the laboratory in undergraduate engineering education." *Journal of Engineering Education,* 94.1 (2005): 121-130.
[2] Thomas, J.W., A review of research on project-based learning. (2000), http://www.bie.org/images/uploads/general/9d06758fd346969cb63653d00dca55c0.pdf, accessed 1/10/2019.
[3] H.A. Hadim and S.K. Esche, "Enhancing the engineering curriculum through project-based learning", *Frontier in Education*, 2002.
[4] Frank, M., Lavy, I., and Elata, D., "Implementing the Project-based Learning Approach in an Academic Engineering Course", *International Journal of Technology and Design Education*, 13, 273-288, 2003.
[5] Chua, K.J., Yang, W.M., and Leo, H.L., "Enhanced and conventional project based learning in an engineering design module", *International Journal of Technology and Design Education*. Vol. 24, Issue 4, pp. 437-458, November 2004.
[Sixty S. Redkar, "Teaching Advanced Vehicle Dynamics Using a Project Based Learning (PBL) Approach", *Journal of STEM Education: Innovations and Research*; Vol. 13, Iss. 3, pp. 17-29, 2012.
[7] E. Sokic and M. Ahic-Djokic, "Simple Computer Vision System for Chess Playing Robot Manipulator as a Project-based Learning Example", *IEEE International Symposium on Signal Processing and Information Technology 2008.* pp. 75-79, 2008.
[8] Krystian Radlak, Marcin Fojcik, "Integration of robotic arm manipulator with computer vision in a project-based learning environment", *Frontiers in Education Conference (FIE) 2015. 32614 2015. IEEE*, pp. 1-4, 2015.

[9] Walter Leal Filho, Chris Shiel, Arminda Paço, "Implementing and operationalizing integrative approaches to sustainability in higher education: the role of project-oriented learning", *Journal of Cleaner Production*, vol. 133, pp. 126, 2016, ISSN 09596526.
[10] B. S. Dridhara and D. H. White, “Developing experiments for the vibration course with minimal expenditure”, *ASEE annual conference* 2012.
[11] R. Ruhala, “Four Free Vibration laboratory Experiments using two Lumped mass apparatuses with research caliber accelerometers and analyzer”, *ASEE annual conference*, 2010.