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Investigations into Engineering Dynamics Theory: A Student-Led Project to Utilize Smartphone Technology

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Journal Publications 1. Luo, Albert C.J. and O'Connor, Dennis (2014), "On periodic motions in a parametric hardening Mathieu Duffing oscillator", International Journal of Bifurcation and Chaos, 24, 1430004. 2. Luo, Albert C.J. and O'Connor, Dennis (2009), "Periodic Motions with Impacting Chatter and Stick in a Gear Transmission System", ASME Journal of Vibration and Acoustics, 131, 041013. 3. Luo, Albert C.J. and O'Connor, Dennis (2009), "Impact Chatter in a gear transmission system with two oscillators", IMeChe Part K: Journal of Multi-body Dynamics, 223, 159-188. 4. Luo, Albert C.J. and O'Connor, Dennis (2009), "Mechanism of impacting chatter with stick in a gear transmission system", International Journal of Bifurcation and Chaos, 19, 1975-1994 5. Luo, Albert C.J. and O'Connor, Dennis (2009), "Periodic motions and chaos with impacting chatter with stick in a gear transmission system", International Journal of Bifurcation and Chaos, 19, 2093-2105.

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Abstract

Due to the technological advancements and proliferation of the mobile-phone industry, smartphones are increasingly being utilized as an educational tool to improve student learning. The purpose of this paper is to consider the use of smartphones as a ready-made tool for undergraduate engineering students to increase both their knowledge and excitement of course material. Such devices have a multitude of onboard sensors which allow for wide-ranging measurement applications. In particular, the accelerometer, gyroscope, and orientation sensors are well suited to measure and quantify dynamical movement. The paper herein is a study of a Fall 2016 undergraduate dynamics course in which students utilized their smartphones to complete a class project. Specifically, students designed and conducted their own experiment to investigate and measure the dynamics within their proposed study. The topics were open to the students' imagination and concerns as long as they considered acceleration measurement and course relevance. Groups were self-selected and consisted of three or less students with a single report submitted for project completion. Three projects are introduced herein to illustrate the diversity and effectiveness of this teaching tool. Finally, a class survey, which was conducted after the projects were submitted, is considered to access if the said project increased both the students' excitement for the course material as well as their sense of understanding.

I. Introduction

At California State University Chico, the civil, mechanical, and mechatronic engineering students are required to complete a junior level course in dynamics (MECH 320). Based on *Newtonian Mechanics*, this course requires students to model and analyze the motion of particles and rigid bodies, with and without forces applied. Historically, this course endures large class sizes and/or multiple sections to accommodate the high volume of students enrolling. As well, the course content of Dynamics has largely focused on homework, quizzes and exams. Not surprisingly, students often suffer difficulty in understanding the key concepts which are mathematically intensive. Worse still, many are unable to appreciate the relevance of dynamics within their respective majors and become disaffected. Including a laboratory component in which students perform several experiments to demonstrate the relevant theory would certainly be helpful. Unfortunately, the instrumentation, equipment, and computers required to complete such an endeavor are extremely expensive. Also, there is currently insufficient lab space at Chico State to hold and conduct such experiments.

On the other hand, given that the vast majority of students now own a smartphone, most students have access to an instrument with remarkable capabilities to measure and record engineering data. In particular, the onboard three-axis accelerometer allows students to measure experimental acceleration and compare to theoretical calculations. Having in mind budgetary and space constraints, as well as student empowerment and excitement in learning, a trial run smartphone project was assigned in the Fall 2016 semester of MECH 320. The goal was simply to bolster student excitement for the course material and improve student learning outcomes. The project was first described in the syllabus as worth 10% of their overall grade and later outlined in more detail with a class handout. To give added incentive, each project was subject to extra credit for demonstrating above and beyond effort and completeness. As well, students were first tasked with self-selecting into groups of three or less and submitting a project description for approval.

II. Assignment

The class handout which outlined the smartphone project requirements is provided on the following page. There were three important aspects to this assignment. First and foremost, the project was open to students' imagination. With the incredible diversity of student backgrounds and interest, the aim here was to not set limits and give students a chance to openly consider their curiosity. Albeit, this strategy may occasionally backfire when students are more comfortable with specific assignments. Secondly, students were required to submit a detailed report with data and engineering analysis. The target here was to encourage students to discern qualitative meaning from their experimentally measured data. Indeed, this ability is particularly important for engineering students and is often only practiced in well-defined instructional laboratory experiments. Finally, the third important aspect to this project required students to utilize their smartphone for much more than they previously thought possible. There is a broader impact to student learning when they are empowered to understand and appreciate the dynamics in everyday situation. This not only helps their own understanding, but also enables them to share their knowledge and tools with friends and family. The class handout which described the smartphone project is given in the following page.

MECH 320 Dynamics, Fall 2016
Instructor: Dennis O'Connor, MMEM, O'Connell 415, dmoconnor@csuchico.edu
Smart Project: Key points and expectations
Due: December 5th, 2016

Subject:
Based on relevant course content and instructor approval, students will design an experiment to investigate and measure the dynamics within the proposed study. Most smart phones are well equipped with accelerometers and high speed cameras to measure acceleration and movement. Groups of three or less may be formed and a single report submitted for project completion. Both a hard copy as well as electronic copy of the report must be provided.

Topics:
Open to students' imagination and concerns, projects may investigate the nature of any relevant dynamical situation so long as safety and decency are preserved. Examples may consider acceleration/velocity measurement and comparison while driving, tumbling, dancing, swinging, impacting, free-falling, etc. Effective application of key course concepts such as Force, Acceleration, Impulse, Momentum, Work, and Energy will demonstrate a successful project. Extraordinary projects will be subject to a 5% extra credit and class discussion.

Report Guidelines:
1. Title Page having project title, group member names, date, course title, and campus.
2. Background with project description with relevant Dynamics concepts and equations.
3. Procedure including equipment and detailed description of project experiment
4. Results giving careful representation of collected field data
5. Conclusions to reconcile the experimental results with the Dynamics concepts and equations
6. Single sided, Times New Roman, size 11 font, typed, double space, standard 1" margins, figures and tables labeled,
equations typed, page numbers, clean, professional.

Notes:
Recommended software and phone apps:
Mathtype http://www.dessci.com/en/products/mathtype/ (Free)
Sensor Kinetics Pro http://www.rotoview.com/sensor_kinetics_pro.htm ($0.99 iPhone) ($2.99 Android)

III. Student Projects

A. Sample 1: "The Coriolis Effect"

The students in this project constructed a homemade apparatus to investigate Coriolis acceleration. Their setup is pictured below in Figure 1 which was taken from their report. The primary goal was to experimentally produce and calculate Coriolis acceleration by utilizing a pair of smartphones to measure angular velocity and absolute acceleration. Finally, a comparison was given to a theoretically calculated Coriolis acceleration.

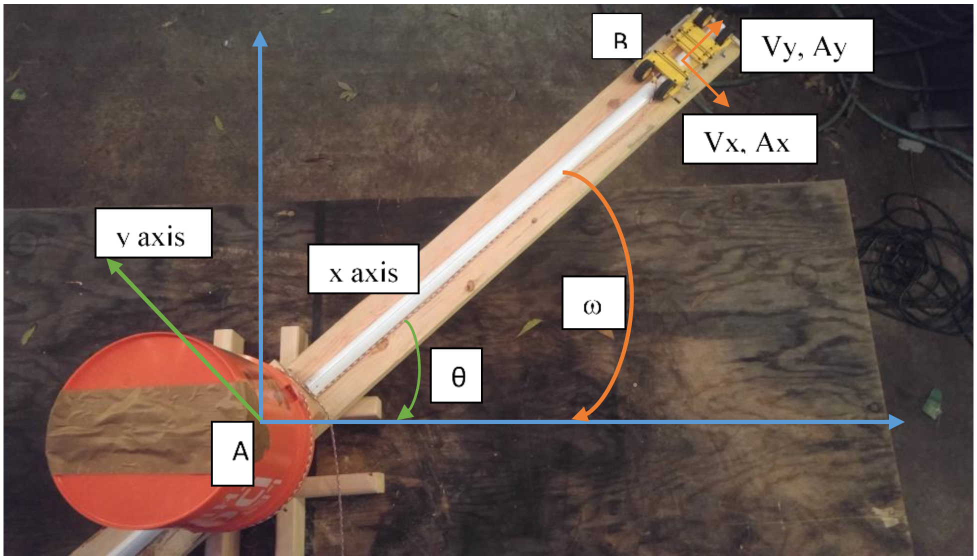

Figure 1 Experimental setup with assigned coordinate system.

Recall that for a rotating reference frame, the equation for absolute acceleration is given by

$$\vec{a}_B = \vec{a}_A + \dot{\vec{\Omega}} \times \vec{r}_{B/A} + \vec{\Omega} \times \left(\vec{\Omega} \times \vec{r}_{B/A}\right) + 2\vec{\Omega} \times \left(\vec{v}_{B/A}\right)_{xyz} + \left(\vec{a}_{B/A}\right)_{xyz}. \qquad \text{Eq.(1)}$$

From Eq.(1), the term which specifically calculates the Coriolis acceleration is

$$2\vec{\Omega} \times \left(\vec{v}_{B/A}\right)_{xyz} \qquad \text{Eq.(2)}$$

Students manually rotated the apparatus with special efforts to maintain a constant angular velocity. A smart phone was placed centered on the axis of rotation which recorded and displayed the angular velocity. Test data from this phone is plotted in Figure 2 on the following page. At the same time, a second smart phone was placed onto the car and pulled with constant speed toward the bucket. With these carefully designed experimental constraints, three of the terms in Eq.(1) became zero and are describe below in Eq.(3).

$$\left.\begin{aligned} \vec{a}_A &= 0 \\ \dot{\vec{\Omega}} \times \vec{r}_{B/A} &= 0 \\ \left(\vec{a}_{B/A}\right)_{xyz} &= 0 \end{aligned}\right\} \qquad \text{Eq.(3)}$$

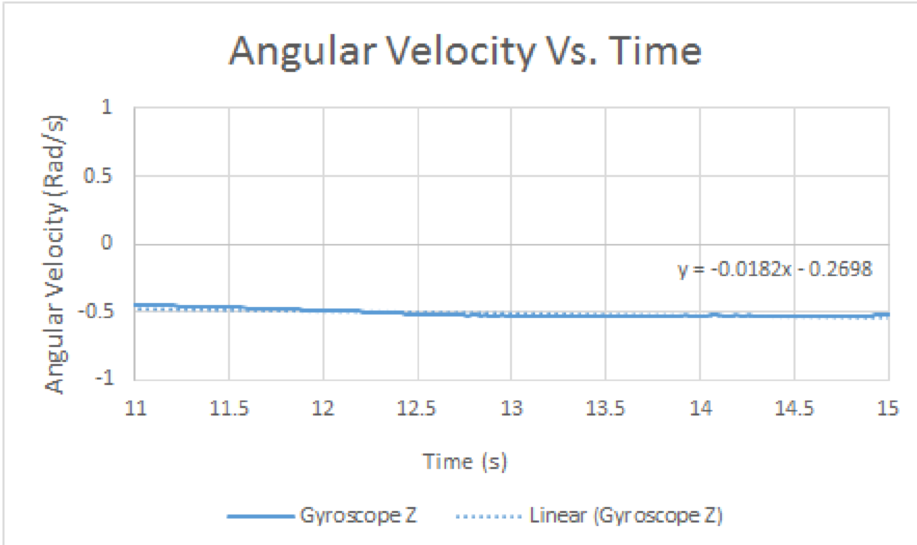

Figure 2 Time history of rotational speed during test.

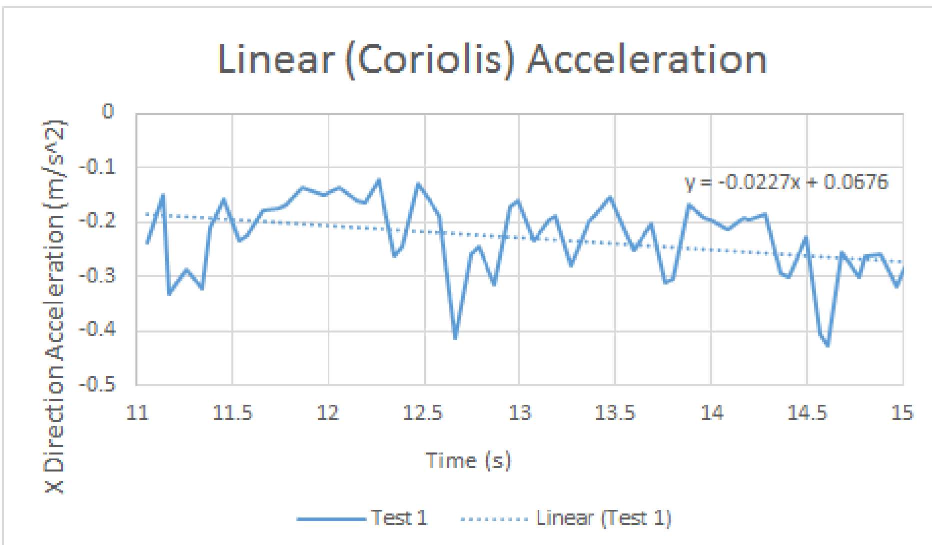

Figure 3 Calculated Coriolis Acceleration.

The students did make one mistake however as they incorrectly disregarded the fourth term $\vec{\Omega}\times(\vec{\Omega}\times\vec{r}_{B/A})$ when solving Eq.(1) for the relative velocity. Their resulting calculation of Coriolis acceleration is plotted in Figure 3 above. For the experimentally determined Coriolis acceleration, the team reached a value of $-0.1305\, m/s^2$ while their theoretical calculation was found to be $-0.1608\, m/s^2$. A sample is given here from the team's concluding remarks:

"*From our data we can conclude that we successfully isolated the phenomenon. We did this by calculating our theoretical acceleration and comparing it to what the sensors actually recorded. Areas of improvement would be a more rigid base, smoother running surface, a constant angular drive and linear velocity for the car.*"

B. Sample 2: “Trebuchet”

The students in this project constructed a homemade launching apparatus known as a Trebuchet. Their setup is pictured below in Figure 4. The primary goal was to compare experimentally measured acceleration and velocity values with that of theoretically determined values during launch.

Figure 4 Experimental apparatus for launching.

Based on Dynamics principles learned in class, the team calculated the mass-moment of inertia for the rotating arm and applied Newton’s Laws to estimate the theoretical angular velocity and acceleration of the launching arm. This was then used as the launch velocity in the projectile motion equations. For testing, one smart phone was mounted to the axis of rotation to physically measure and record the rotational velocity. As well, a second smart phone was mounted to the end of the launching arm to measure and record the tangential and angular acceleration. Finally, several launches were conducted with a tennis ball and a comparison was given between the experimental and theoretical launch results for launch distance.

For each launch, the travel distance was measured and the results are given below in Table 1. These values represent the experemental result of projectile motion and average to 7.933 *ft*. As well, on the following page, an example of the measured angular velocity and acceleration from their smartphones are given in Figure 5 and 6, respectively. From Figure 5, the angular velocity increased linearly and reached 5.086 rad/s upon launch. Based on kinematics and Newton’s Laws, the team’s calculated angular velocity was 4.43 rad/s. Furthermore, the measured and predicted angular accelerations were 7.8765 rad/s^2 and 8.232 rad/s^2, respectively.

Table 1 Launch distance for ten trials.

Test	1	2	3	4	5	6	7	8	9	10
Distance(ft)	8.166	7.75	7.75	7.833	7.583	8.166	7.916	7.833	8	8.33

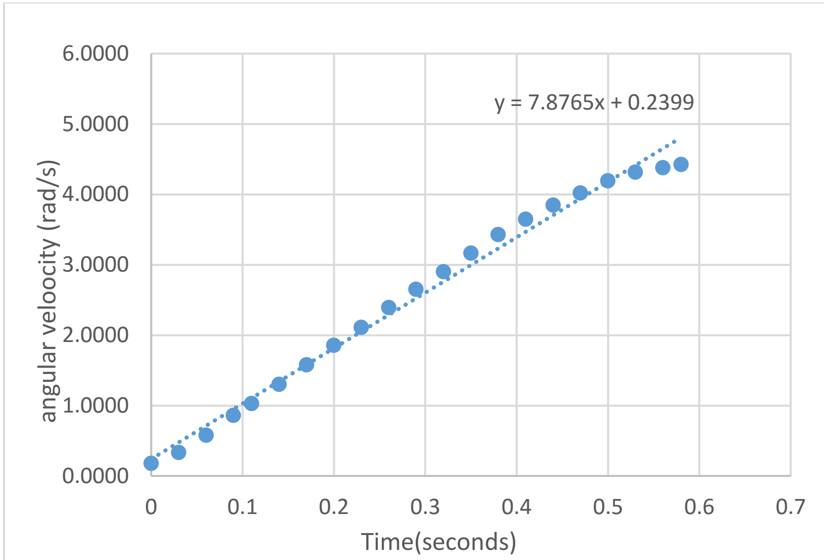

Figure 5 angular velocuty of the Trebuchet during launch.

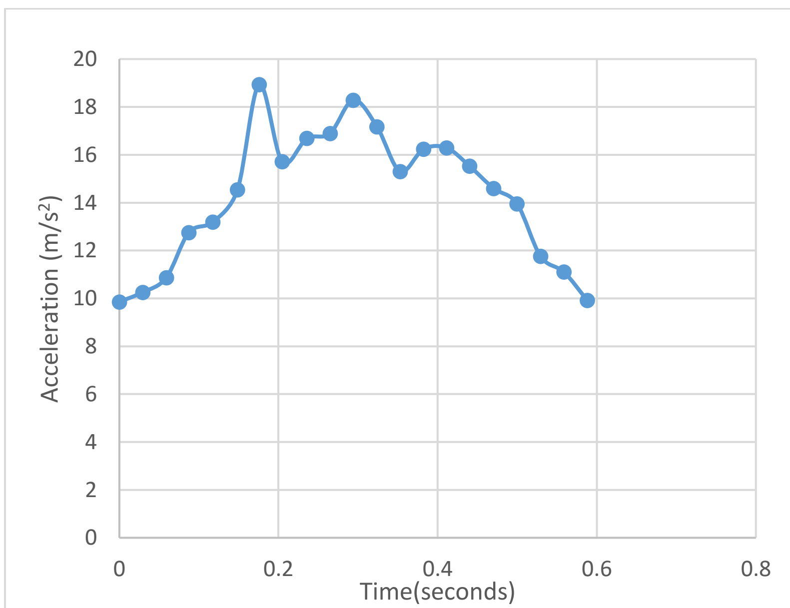

Figure 6 Magnitude of acceleration at the end of launching arm.

To finish, the team predicted the distance that the ball would travel based on the measured angular velocity to be 8.57 *ft*. The difference between the predicted and average measured launch distance was about 7 inches. A sample is given here from the team's concluding remarks:

"*Using dynamics principles, we were able to calculate a variety of things about our trebuchet. We were able to calculate its angular acceleration and velocity, using moment of inertia. This allowed us to also calculate the velocity of the ball as it left the lever arm. We were able to use kinematics to then determine the distance the ball would travel. We were able to tests these results, by actually launching our trebuchet. All of our actual values, were slightly lower than calculated, which we expected, because we didn't account for internal friction.*"

C. Sample 3: "Calculating Wheel Horsepower in Motorcycles Using Accelerometer Data"

The purpose of this student project was to calculate the wheel horsepower in a 1999 Harley Davidson Sportster 1200, a 1986 Kawasaki KLR600, and a 1981 Honda Elite CH80 using accelerometer data. A picture of the Kawasaki motorcycle with a smartphone mounted in Figure 7 below.

Figure 7 Motorcycle with smartphone mounted.

Based on Newton's Laws, the measured acceleration of the motorcycle was utilized to determine the wheel's static friction force. The motorcycle velocity was measured by visual inspection of the speedometer, and utilizing the basic power equation of force multiplied by velocity, the students calculated the wheel horse power. The data for this project was collected using a smartphone and the *Sensor Kinetics* smartphone application. The students in this project faced a particular challenge with vibration noise due to the running engine. This made determining the actual acceleration of the motorcycle difficult as they had no experience in digital signal processing. A sample of accelerometer data is plotted below in Figures 8 and 9.

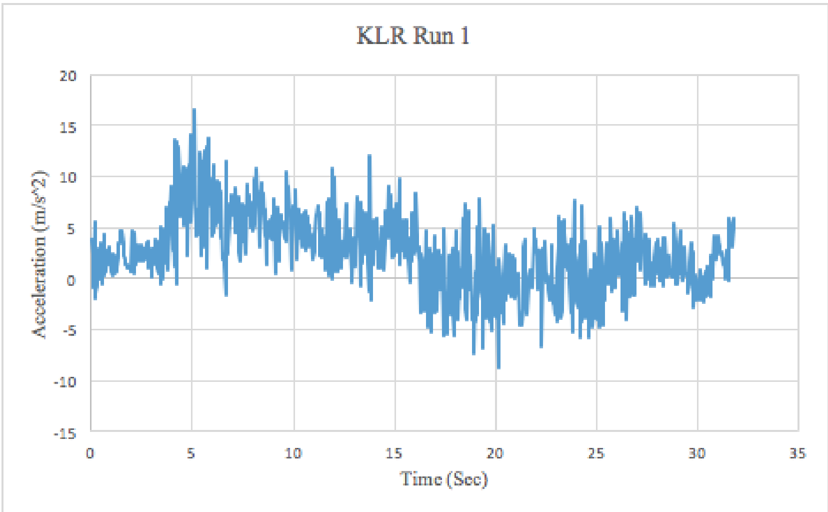

Figure 8 Smartphone recorded acceleration data from the Kawasaki.

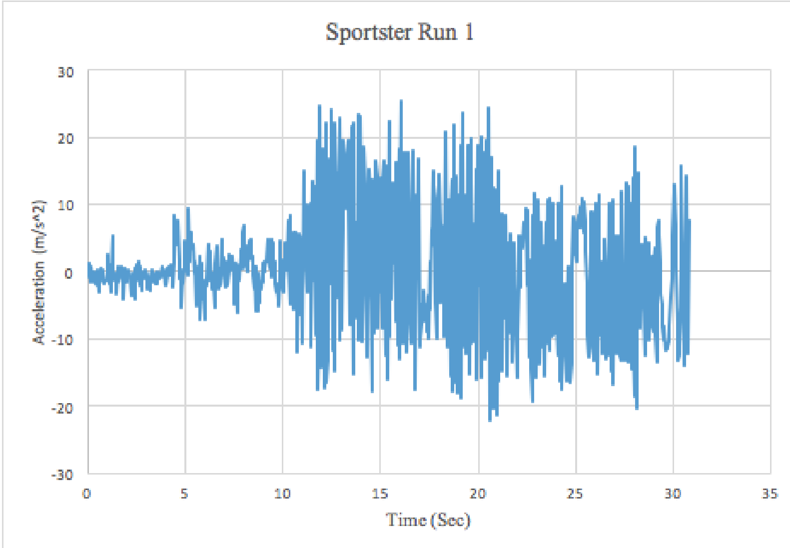

Figure 9 Smartphone recorded acceleration data from the Sporster.

By taking a trend-line, the students approximated the motorcycle acceleration and correlated the timing with their given velocity. Next, the mass of the motorcycle and rider provided the total mass and was multiplied by the acceleration to calculate the net static friction force provided by the wheel. This was then multiplied by velocity to determine the wheel horsepower. The results for the three motorcycles are summarized below in Table 2.

Table 2 Comparison of calculated wheel horsepower and manufacturer's published values.

Name	Mass (kg)	velocity (mph)	Velocity (m/s)	Max acc. (m/s^2)	Power (W)	Power (Hp)	Published Hp
Derek	249	32	14.28571429	7	24900	33.391398	41.72
Dan	154.2	20	8.928571429	3.5118	4834.9961	6.4838264	6.4
Neil	324.7	36	16.07142857	11	57402.321	76.977661	67.7

Althought the students in this project relied on crude approximations and noisy data, their results were were remarkably close to the published data. Furthermore, they managed to appreciate and deal with vibration issues and phenomena usually discussed in graduate level courses. More importantly, from their report there was clear indication that they thoroughly enjoyed and appreciated the assignement. A sample is given here from the team's concluding remarks:

"*The main downfall of this experiment was the amount of vibration generated by the motorcycle engines and road…Due to the smoother engine (in comparison to the Harley's V-Twin) and the long-travel suspension, the KLR had the least vibration out of the motorcycles and therefore had some of the cleanest data. It was certainly satisfying to see that the KLR makes about as much power as we expected it to…All in all, we were able to calculate horsepower with a reasonable amount of accuracy and were able to complete our experiment successfully. There were some unexpected challenges but we were able to rise above them and get the data that we needed.*"

IV. Student Survey

Following the project deadline and online submission of reports, a student survey was conducted in-class to assertain the overall effectiveness of the smart phone project. The survey consisted of five questions, three were simply yes/no with room for comments and 2 were stricly asking for comments. The questions are listed below in Table 3.

Table 3 Student survey questions given in class.

1	Did this project increase your knowledge and understanding of Dynamics Theory? Yes / No
2	In terms of experiment, measurement, and theory, was your project an overall success? Yes / No
3	Did this project increase your interest or excitement for Dynamics? Yes / No
4	What (if any) were the major difficulties for this project?
5	Please provide comments or suggestions for how this project could be improved.

Of the 79 students enrolled in this section of Dynamics, only 49 students were attending class when the survey was administered. As such, the results are necessarily subject to a sampling bias. This is likely the result of timing as the survey was given on the last day of scheduled lecture when students notoriously do not attend class. Nevertheless, the results for the first three questions are plotted below in Figure 10. The blue and red columns represent the count of students answering yes or no, respectively. Most importantly, 44 students answered yes to question 1 which means that most students felt that their knowledge and understanding of Dynamics was increased through this project. The comments written with this question were telling and many, one such example points to a key success:

"*Don't Like Coriolis but understand it more*."

Students often begrudge the more difficult concepts of Dynamics which are heavily mathematical, so finding a novel way to help their understanding is invaluable.

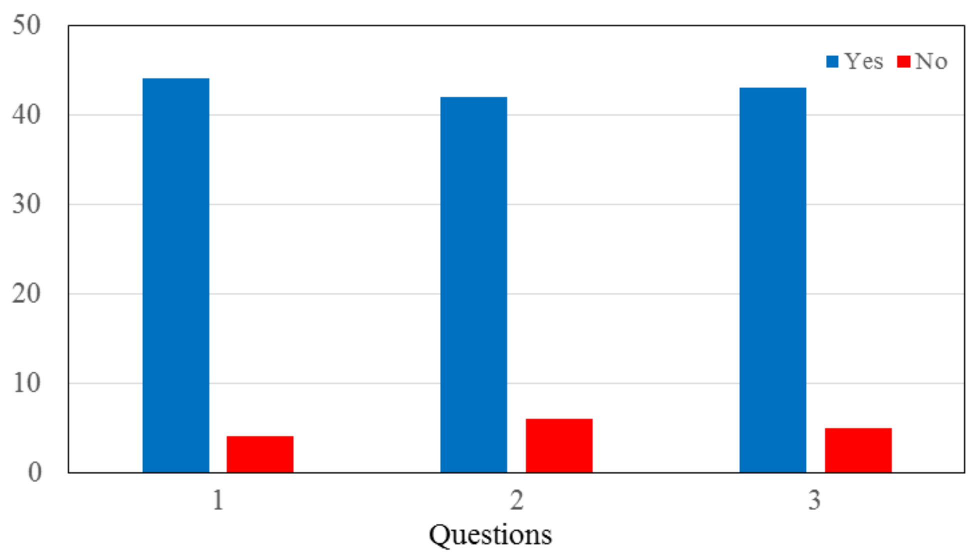

Figure 10 Chart of student survey results to yes/no questions.

Regarding the success of the student projects, only 6 answered no to question 2. Several student comments helped to explain their difficulties, one such example:

"*Our setup was too sloppy, and our results were not what they should have been*."

One of the primary goals of the smart phone project was to increase student excitement for Dynamics. From the response to question 3, there is clear indication that this project was highly influential. One comment sums up all the others:

"*I think about Dynamics in my everyday life now!!!*"

The fourth question in the survey was designed to help improve future student projects by revealing the major difficulties. Since this was the first implementation of the smartphone project, little was known about how the students would handle a loosely defined project. In subsequent semesters, the learned difficulties can be address in-class. Based on the comments from this question, two main themes were present. First, groups had difficulty finding time to work with each other and the due date coincided with many other semester-end projects. Naturally, several students had procrastinated until the impending deadline and thus had difficulty in finishing the project. In future semesters, this project will be due two weeks prior to finals week and more frequent reminders for the due date will be announced. Secondly, the students had difficulty in making sense or utilizing their engineering data. This is not surprising because undergraduate students have extremely little practice in designing their own experiments. One comment captures this issue quite well:

"*Maybe more guidelines on what is expected to be calculated. I like designing my own experiment but I wasn't sure what my goal was*"

Indeed, the project statement did not have specific instructions for measurement and comparison, so future project descriptions may include additional details and examples. Nevertheless, this project offered a unique opportunity to help students with the practice of designing and conducting their own experiment. Lastly, the fifth question was asked to learn ways of improving the project. There were far less comments written here, but a few did express excitement at learning what other students did for their project. As one such student put:

"*Make Presentations necessary – I want to see what everyone else is doing…or have each group post a bit in discussion board on Blackboard*."

V. Conclusion

As to the goal of this project increasing both student understanding and excitement for Dynamics theory, there was clear evidence of success. The student survey documented the remarkably positive attitudes and perspectives of the students and offered insight into how this project could be improved. Furthermore, several in-class discussion throughout the semester demonstrated a sustained excitement for the projects. There was also a competitive nature to this project in that students thought long and hard to have the best project and often teased each other about whose project was "coolest". The diversity of projects completed was astounding. They ranged from analysis of ceiling fans to acceleration during aerobatic maneuvers, and from Coriolis acceleration of toy cars to the skid out conditions of automobiles. Reports varied in their depth of completeness, but they were consistently professional with equations typed, figures labeled, and results well documented. Several reports had action pictures of students performing their experiments with friends and family. With the overwhelmingly positive feedback from the student survey, as well as the remarkable nature of the reports, this first student-led investigation project into dynamics theory was an absolute success and will become a mainstay to future semesters of Dynamics.

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