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Blended Learning in a Rigid-Body Dynamics Course Using On-Line Lectures and Hands-On Experiments

Prof. Aldo A. Ferri, Georgia Institute of Technology

Al Ferri received his BS degree in Mechanical Engineering from Lehigh University in 1981 and his PhD degree in Mechanical and Aerospace Engineering from Princeton University in 1985. Since 1985, he has been a faculty member in the School of Mechanical Engineering at Georgia Tech, where he now serves as the Associate Chair for Undergraduate Studies. His research areas are in the fields of dynamics, controls, vibrations, and acoustics. He is also active in course and curriculum development. He is a Fellow of the ASME.

Dr. Bonnie H. Ferri, Georgia Institute of Technology

Dr. Bonnie Ferri is a Professor and the Associate Chair for Undergraduate Affairs in the School of Electrical and Computer Engineering at Georgia Tech. She performs research in the area of active learning, embedded computing, and hands-on education. She received the IEEE Education Society Harriet B. Rigas Award.

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Abstract

Rigid body dynamics is a foundational course that forms the basis for much of the ME curriculum in the mechanical systems area. Under the best of circumstances, the topic is challenging, but especially so when both two-dimensional (planar) and three-dimensional rigid body dynamics are covered in the same 3-hour semester class. To address these challenges, several changes were implemented in a section of Rigid Body Dynamics in the Fall of 2014 and continuing into Spring 2015. First, in class lecturing was replaced with online videos developed for two Coursera MOOCs on dynamics. Second, various types of active learning were introduced into the classroom. Of particular concern in this paper is the inclusion of experiments into the lecture portion of the class. These experiments are described in this paper and assessment results from the two sections of dynamics are presented and discussed. It was found that the students reacted very favorably to the experiments, as seen by a comparison of pre-, post-, and longitudinal surveys. It was also seen that experiments where students actually touched and performed the experiments were perceived as more valuable to the students compared with experiments performed by the instructor.

1. Introduction

Blended or hybrid learning environments have been used in several fields as a way of improving student learning. Blended learning is an extension of flipped classrooms, where students watch lecture videos prior to class and come to the class period to work extra problems and homework [1-2]. Like flipped classrooms, blended learning makes use of the lecture videos watched before class, but then the class period can be filled with a blend of different activities such as supplemental lectures, hands-on learning with experiments, collaborative learning, problem solving, inquiry-based learning, and student-led instruction. A number of studies have investigated the effectiveness of flipped and/or blended classes in relation to traditional lectures and have found interesting results [3-7]. Although learning outcomes are somewhat mixed, student perceptions of flipped classrooms are generally positive overall.

In the Fall of 2014 and Spring of 2015, a series of learning experiments were conducted in a sophomore-level rigid-body dynamics class in the School of Mechanical Engineering at Georgia Tech. Rigid body dynamics is a foundational course that forms the basis for much of the ME curriculum in the mechanical systems area. Unlike many introductory dynamics classes where only planar rigid-body dynamics is covered, the class taught at Georgia Tech is relatively challenging as it covers up through three-dimensional rigid body dynamics and work-energy, within a 3-credit-hour format. The class is required for the BSME degree and follows upon prerequisite courses on calculus-based Physics I, integral calculus, and Statics. The course is a direct prerequisite to several other classes in the curriculum including System Dynamics, and Fluid

Mechanics, which are in turn pre-requisites to other courses such as Measurements and Instrumentation Lab, ME Systems Laboratory, and Heat Transfer.

The Dynamics class is often remarked by students as being the hardest in the ME undergraduate curriculum. One of the biggest hurdles is spatial visualization and inexperience with problem solving skills which are so important to doing well on tests and exams.

In the Fall of 2014 we decided to run a section of Dynamics in flipped mode in order to move lecturing outside the classroom. This freed up face-to-face time in the classroom for more active and collaborative forms of learning such as group-based problem solving sessions, and in-class experiments. The video modules were from two MOOCs designed for the Coursera platform: *Engineering Systems in Motion: Dynamics of Particles and Bodies in 2D Motion* and *Advanced Engineering Systems in Motion: Dynamics of Three Dimensional (3D) Motion*, both by Wayne Whiteman of Georgia Tech. The videos were very well produced and were targeted at the same level as the dynamics class in question. Conveniently, the MOOCs used the notation and examples from the course textbook that has been used for many years at our university: *An Introduction to Dynamics, 4th Edition* [8]. Video modules were typically short- on the order of 6 to 12 minutes in length. The first MOOC consists of 47 videos roughly corresponding to 10 weeks of our dynamics course. The second MOOC consists of 35 videos roughly corresponding to last 5 weeks of the class. Each class opened with a short quiz based on video and textbook material assigned for that class period. These quizzes were akin to concept-inventory questions, which emphasized concepts rather than formulaic knowledge or algebra. The mode of delivery is similar to other courses that have used MOOCs to flip courses, such as the circuits courses taught at Georgia Tech [9]. It should be mentioned that the style of implementation could be better classified as “blended” or “hybrid,” since class time was also used for just-in-time lecturing, or for instructor-led problem solving exercises at the board. The dynamics section studied in Fall 2014 had a size of 76 students, and was one of 4 sections of the course offered that term. The study was continued in Spring 2015 by the same instructor for a course of size 67, which was one of 5 sections of the class offered that term.

Students watched video modules prior to each class, which freed up class time for other activities. Of particular interest in this paper is the inclusion of hands-on experiments performed in the lecture room, which were found to have a notable effect on student learning in prior research by the authors in the context of a circuits and electronics course for non-majors [7] and [9].

In the Fall of 2014, two experiments were introduced on topics that students in prior semesters have found difficult: centripetal acceleration and rolling kinematics. The centripetal-acceleration experiment involved a cart equipped with a smartphone and a large circular track. The rolling kinematics experiment involved a circular disk rolling on a slight incline. Students used the free *Tracker* software to measure the motion of various points on the moving objects. In Spring 2015, a set of pendulum-like devices were constructed to hold student-owned smartphones to measure accelerations. Surveys were conducted at the beginning and at the end of the semester to determine student perceptions of the blended learning environment as well as the hands-on experiments.

Section 2 contains background material on the learning science behind hands-on learning. Section 3 describes the experiments more fully. Section 4. Presents survey and assessment results and Section 5 concludes with final observations.

2. Background on Hands-On Learning

Laboratory experiences are an essential part of engineering curricula. Traditionally, laboratories have given students an opportunity to learn through observation, to examine the accuracy of theoretical models, and for the development of professional skills of value in engineering industries. With the increasing availability of computational and networking power, a debate has evolved about the continued necessity of laboratories. Couldn't students attain the same experiences of hands-on labs through use of virtual or remote labs? The debate is nicely summarized in several references, for example [10-12]. While there is no doubt that virtual and remote labs are very useful in many circumstances, we argue that the effectiveness of hands-on labs in the context of student learning is superior, especially in foundational classes.

A watershed in the debate over which type of lab is better occurred in 2002 when a colloquy of experts from a wide range of disciplines and institutions convened to determine the fundamental objectives of laboratories, regardless of the method of delivery. They converged on 13 learning objectives [10]: working with instruments, building a model, devising an experiment, data analysis, design, learning from failure, creativity, psychomotor, safety, communication, teamwork, communications, ethics, and sensory awareness. The proposed effort will determine the extent to which these objectives should be met for mobile hands-on labs. In contrast, remote laboratories and virtual laboratories are unable at this point to address objectives 8 and 13 (psychomotor and sensory awareness.) Touch, in particular, may be underappreciated as a component in student learning, since it can increase students' long-term memory and recall of the phenomena.

One of the drivers of the debate is the increasing complexity and expense of laboratory equipment. In order to give students a taste of the current state-of-the-art in industry and in graduate research labs, university faculty have sought to acquire highly accurate and sophisticated tools, which must be housed in dedicated laboratory spaces and maintained by teaching assistants who can demonstrate their use to undergraduate students. In contrast, the laboratory experiences proposed in this research are purposely designed to be portable, affordable, and when possible, student owned, and address as many of the laboratory learning objectives outlined in Reference [10] as possible when implanted in a standard lecture-based course. In addition to lecture-based classroom settings, the portability and affordability of these small experimental platforms opens up the possibility of reaching students in non-traditional settings such as MOOC's as well as traditional asynchronous distance learning modes.

Lectured-based classes can benefit significantly from the inclusion of experiential learning activities, such hands-on experiments, because they can influence memory and recall. According to the Levels-of-Processing theory [13], memory and recall are dependent on the depth of mental processing during the learning process. Deeper levels of thought result in more elaborate, persistent, and stronger memories than more superficial levels of thought. Likewise, memory is enhanced when multiple sensory modes are activated- vision, hearing, touch, and smell. The theory of memory encoding [14] is also relevant to hands-on learning. The four senses of vision, hearing, touch, and smell are processed with different parts of the brain; for example, tactile encoding is associated with the somatosensory cortex of the brain [15]. Tactile sensing of physical experiments may reduce the cognitive load of a learner's working memory and thus support more complex understandings [16]. Since each sensory type (visual, auditory, touch) has its own processing channel in the brain, learning can be facilitated by the cognitive load being borne by different channels such as visual, tactile, or auditory channels. This may be the reason that concepts reinforced through hands-on experiments might be retained much more effectively than concepts learned through traditional or even active learning techniques in the lecture classroom.

One of the often-cited reasons for requiring experiments and laboratories in science and engineering education is to "enhance conceptual understanding" [11]. And as active learning methods, it might be expected that hands-on experiences will always outperform traditional or passive learning methods. Unfortunately, the benefits of hands-on learning are not always realized due to poorly designed experiments [12, 17-19]. Hands-on activities that are done without opportunities for reflection and metacognition have missed the opportunity to create deeper understanding [17]. Shavelson, et al. [20] refer to four different types of knowledge: declarative knowledge ("knowing that"), procedural knowledge ("knowing how"), schematic knowledge ("knowing why"), and strategic knowledge ("knowing when, where, and how our knowledge applies"). This framework provides a useful way of evaluating laboratory experiences; what is typically termed "inquiry based laboratory exercises," are ones that reach the higher levels of the knowledge taxonomy [12]. Pre-labs and other types of preparation are also important as identified in Kolb's experiential learning cycle [21] and [18]. Without "just in time" lectures and pre-labs, the lab session can turn into a formulaic following of the lab manual instead of actively constructing meaningful knowledge from it.

Vertically Integrated Program on Hands-On Learning

The primary mechanism for the design of new experimental platforms for the dynamics course is the Vertically Integrated Program (VIP) Hands-On Learning Team at Georgia Tech, established in 2015 under an NSF grant and advised by the two authors of this paper. The VIP program gives undergraduate students course credit to pursue research and design experience on projects that last over multiple semesters. The VIP program is offered at a national consortium of 17 colleges and [http://vip.gatech.edu/new/vip-consortium]. We established our VIP Hands-On Learning team in Spring of 2015 with 10 undergraduate students from ECE and ME to design experimental platforms for use in classes.

3. Hands-On Experimental Platforms

In order to supplement the other active learning experiences used in the class, several experiments were envisioned that could be implemented in the lecture class. The criterion for selection of experiments was: (1) What do students have most difficulty in learning? (2) What new technologies exist that can be leveraged to create small portable experiments? (3) What hands-on activities would be most effective in learning and retaining new concepts? (4) How can the measurements be quantified so that comparisons can be made between theoretical predictions and experimental results? Two experiments were designed in the summer of 2014, and implemented in a section of dynamics in fall 2014.

Rolling Contact Experiment

One concept that students have great difficulty in understanding is that of rolling contact shown in Figure 1. For planar motion, the confusion centers on two concepts: First, the contact point between the disk and a stationary surface has instantaneously zero velocity; i.e., it is an instant center of velocity. Secondly, the point of contact does not have zero acceleration. In the first case, students have a difficult time believing that the contact point can be momentarily at rest. Once they see that, they have trouble reconciling that the contact point has zero velocity but has high acceleration away from the contact plane.

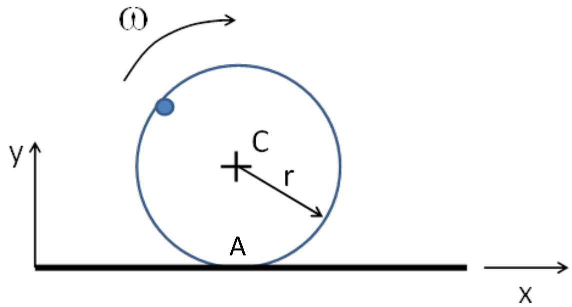

Figure 1: Schematic of pure rolling in planar kinematics

To clarify the situation, an experiment was designed that could show students both phenomena. Since the disk needs to roll several feet, the only feasible way of quantifying the motion was using the video software program *Tracker* [http://physlets.org/tracker/]. A disk of diameter 5 inches having a red dot on the rim was rolled very slowly across a flat surface having a very small incline. Figure 2 shows a snapshot of the disk as it rolled on the surface. Figure 3 shows a Matlab plot of the data gathered from the Tracker software, showing the 2-dimensional motion of the red dot point on the rim. The shape is a cycloid, and the cusps that are clearly evident when the rim point touches the ground are characteristic of high vertical acceleration and zero horizontal acceleration. The experiment was performed at the beginning of a 50-minute class period by the instructor and a TA on a table at the front of the class with students watching from their seats. The motion was captured using a smartphone and was immediately disseminated to the students for quantitative analysis using the Tracker software. Students spent the rest of the class period working in groups to analyze the video and to answer questions in a worksheet. The questions were scaffolded so that the students first computed the speed of the disks center and the rotation rate of the disk. They then used the values of v and

Figure 2: Disk rolling without slip on a flat, inclined surface

ω to predict the acceleration of the contact point. Finally, they compared their predictions to the actual measured acceleration of the contact point to evaluate the correspondence between theory and experiment.

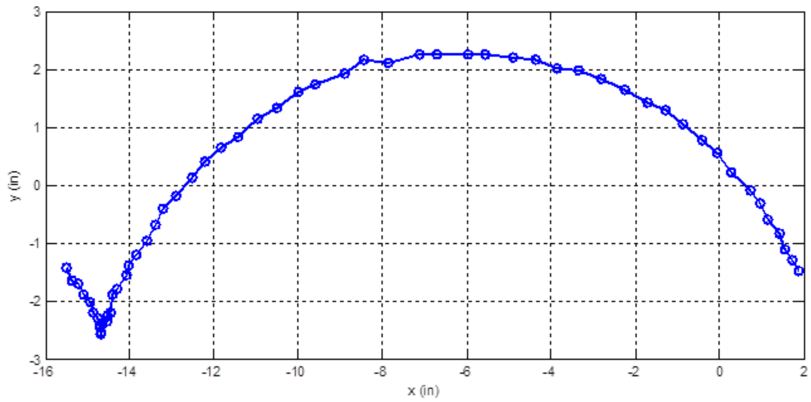

Figure 3. Matlab plot of Tracker displacement calculation

Several performance assessments were conducted to determine the ability of students to learn from the rolling contact experiment: two related quiz questions were given to students on the class meeting directly following the in-class experiment. The quiz was closed-book and closed notes, and students worked individually. The students were given a drawing similar to that shown in Figure 1 above. They were then given a multiple-choice question with four possible choices for answers:

A circular disk of radius R rolls without slipping on a stationary surface at point A. The velocity of the disk's center is v_C to the right. Which of the following statements is true?

(a) $\vec{v}_A = \vec{0}$, (b) $\vec{a}_A = \vec{0}$ (c) $\vec{a}_A = \frac{v_C^2}{R}\vec{j}$ (d) Both (a) and (c)

Of the 72 students who answered this question, 90.5% chose the correct answer of (d). On the same quiz, students were asked to "draw the path of point B as the disk rolls to the right." Figure 4 shows three student responses showing a sample of the types of sketches drawn in response to the question. Out of 72 students who took the quiz: 58/72 (80.6%) got it essentially correct; 10/72 (13.9%) drew more of a sinusoid; 4/72 (5.6%) got it fundamentally wrong.

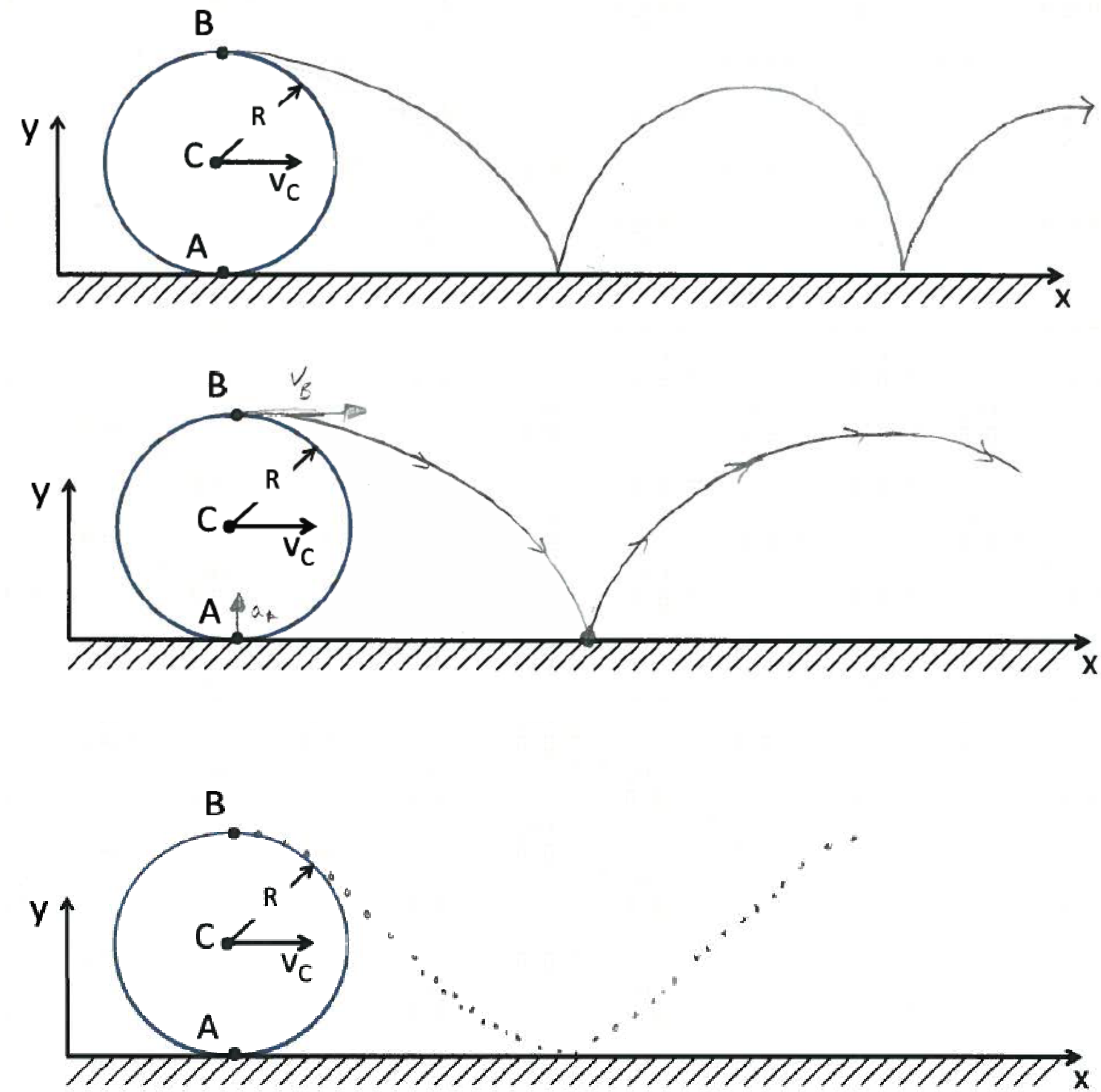

Figure 4: Two examples of where students got the qualitative question basically correct and a third example in which a student drew more of a sinusoidal shape.

As a further testing of the concept of rolling contact, the final exam contained a problem concerning three-dimensional rolling contact. They were asked to analyze rolling contact of a wheel in steady precession, relating the spin rate to the precession rate. A follow up question asked them to give the acceleration of the contact point. Surprisingly, none of the students stated that the acceleration of the contact point was zero. As one of the authors of this paper has taught dynamics at the undergraduate and graduate levels for 30 years, this is an unusual occurrence- there is always at least one student who carelessly asserts that the contact point has zero acceleration.

Centripetal Acceleration Experiment- Original Design:

A common source of confusion among students is the direction of reaction forces applied onto an accelerating body from the surroundings. An experiment was conceived that would utilize a cart rolling inside a vertical, circular track. Figure 5 shows the general arrangement. Two different techniques were used to measure the motion: accelerometers and video processing. For acceleration, we took advantage of the 3-axis accelerometers that are integral to modern smartphones. An app was used to log the accelerations over the course of the motion and to store the data for further processing by students during the class period. At the same time that the acceleration was being collected, a video capture from another cell phone was used to record the motion of the cart. Students used a video processing software *Tracker* to quantify the motion. The video frame rate of the cell phone was only 30 frames per cycle, so the size of the track needed to be quite large in order for there to be an adequate number of frames over the duration of one trajectory of the cart. As seen in Figure 5, the diameter of the track was 7 feet, and was heavy so that the experiment was wheeled into class and the experiment was performed at the beginning of a 50 minute class. Again, the experiment was performed by the instructor and a TA with students watching from their seats. Figure 6 shows a still frame viewed using the tracker software. (The background shows the door to the classroom, which gives the reader a good sense of the size and scale of the experimental system.) The video captured from several trials of the experiment were immediately distributed to the students so that they could process it using Tracker software. Also distributed to students were the accelerometer traces logged by the smartphone. A sample of such an accelerometer trial is shown in Figure 7. It is worth noting that the accelerometer signal is extremely noisy. The "noise" is actually high-frequency vibration that was present as the cart rolled on the surface of the track. In developing the prototype for the track, great care was taken to make the track surface as smooth, frictionless, and circular as possible. But the high-frequency vibration could not be fully eliminated.

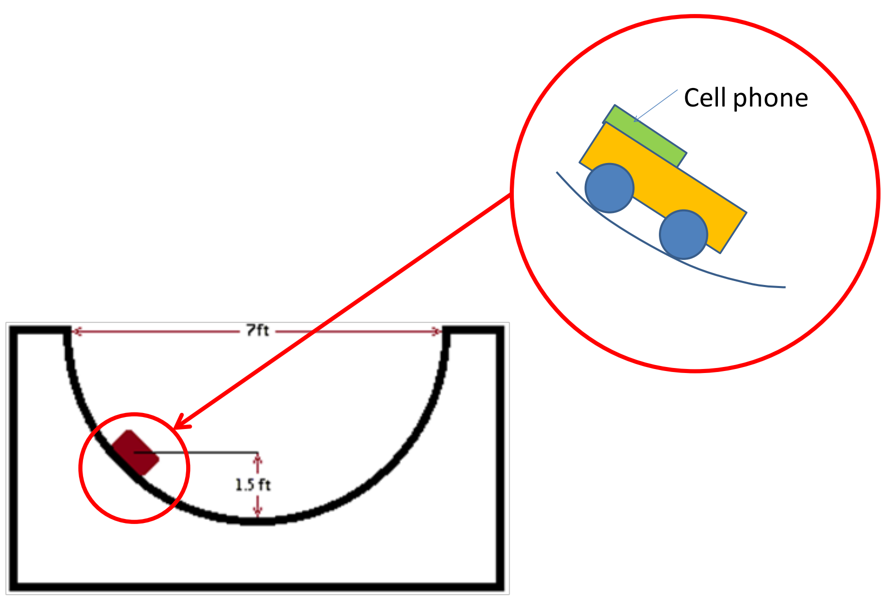

Figure 5: Depiction of the centripetal acceleration experiment consisting of a cart rolling on a circular track.

The in-class worksheet that students completed led students through a process of predicting the acceleration experienced by the cart at the bottom of the track after being released from rest from a higher spot on the track. The students used a work energy approach to obtain the velocity of the cart, and then used this value to compute the centripetal acceleration as v^2/R. Disagreements between the measured values of acceleration and the theoretical predictions allowed the students to appreciate limitations of the theory, and the results of various "real-world" effects such as friction and the fact that the cart-smartphone was not a point mass. The kinetic energy of the cart was not solely translational (as it would be for a point mass) but also had kinetic energy in the form of the kinetic energy of the wheels and of the rotation of the cart itself.

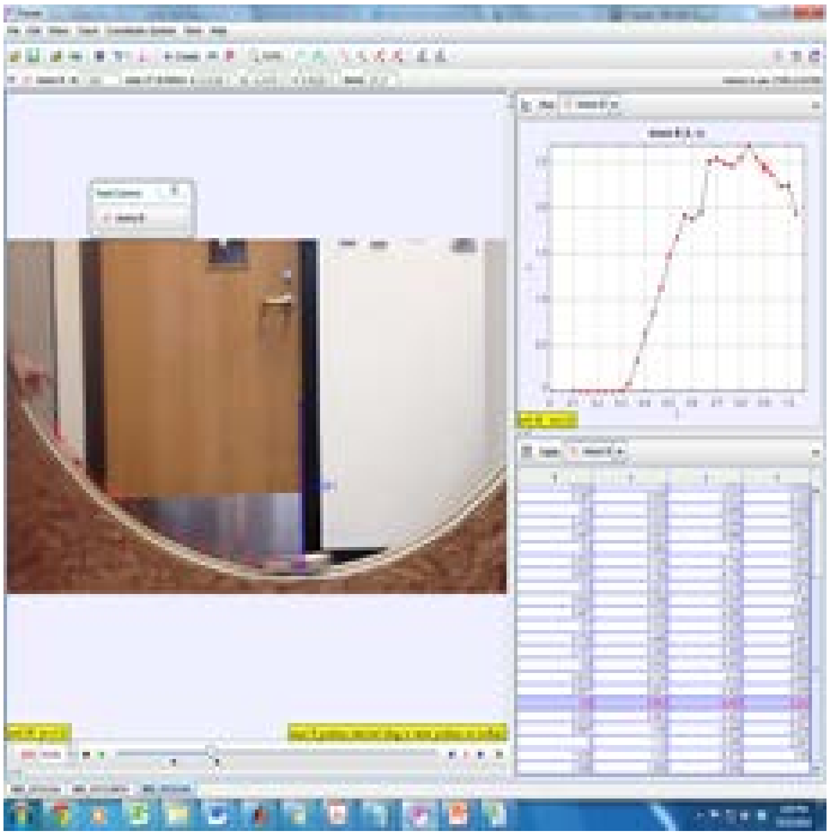

Figure 6: Still frame from the video used by the Tracker software.

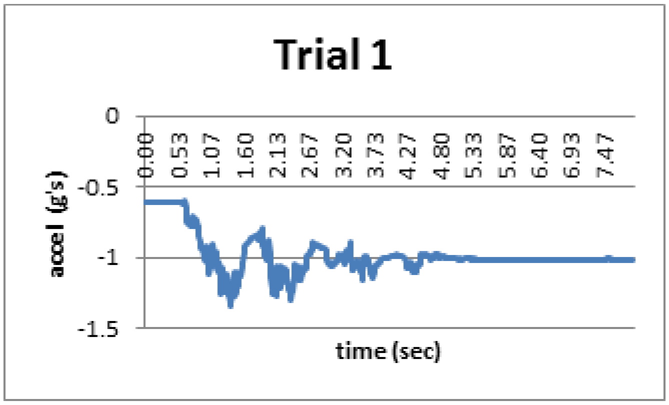

Figure 7: Cell phone accelerometer log.

In the assessment data gathered in the post-survey of Fall 2014 (discussed more fully below), it was revealed that students liked the experiment, but they expressed frustration that they could not perform the experiment themselves. Table 1 shows sample responses collected at the conclusion of the Fall 2014 semester. In response to the free-response question "what would you change about this course," making them more hands-on was mentioned 22 times. Based on the student reaction, a new centripetal acceleration experiment was designed that was portable, compact, and very robust in its operation so that students could do the experiment themselves. This experimental platform was designed by students in the Hands-On Learning VIP group discussed above. The team designed, tested, refined, and fabricated 15 platforms for use in the Spring 2015 offering of the dynamics class.

Table 1: Aggregated responses from open-ended question on "What would you change in the use of experiments in this class?" Fall 2014

Issue	Times Mentioned
Make them more hands-on	22
Have more complex/sophisticated experiments	12
Eliminate experiments or replace them with videos	11
Reduce difficulty with tracker software	7
Give more time in class to complete	6
Make it easier to see (done by professor at front of room)	6
Reduce emphasis on actions instead of understanding	4

In the Spring of 2015, the VIP Hands-On Learning team was given the task of making a much smaller device that would be much more robust and easier to use. The device that students designed was small, elegant, and performed extremely well. Shown in Figure 8, the *Table-topper* consisted of a small pendulum (arm length 20 inches) that could be attached to a classroom desk. At the end of the arm, a special holder was designed that could an Android phone, an iPhone, or a National Instruments myRIO. The acceleration was measured using the internal 3-axis accelerometer in the phone, and logged using a free app available to the students. During a 50-minute lecture, the students measured the acceleration, and compared the peak acceleration against the theoretical prediction. Figure 9 shows an example of an accelerometer log from an experiment involving several swings of the arm after being released from rest. Of note if the fact that the trace is very clean, which was a distinct advantage of the Tabletopper to the large track experiment described above.

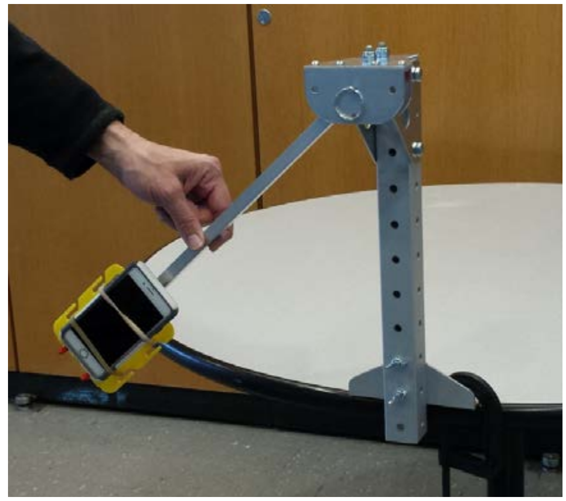

Figure 8: Table-topper centripetal acceleration experiment.

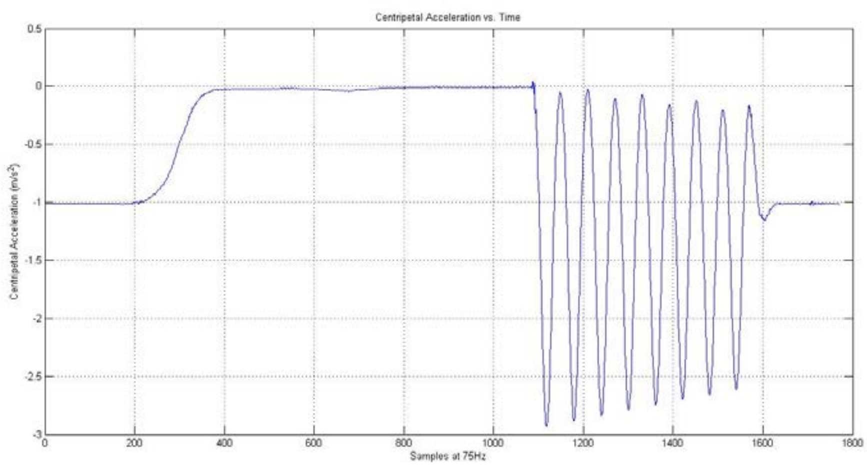

Figure 9. Accelerometer measurement from Tabletopper.

In end-of-term surveys, students expressed very positive reactions to the experiment. The VIP group has also tackled other dynamics topics that are generally considered difficult to learn. In the Fall semester of 2015, they designed a small portable platform to demonstrate four-bar mechanisms and slider-crank mechanisms. Students in the dynamics class have a surprisingly difficult time visualizing how these devices work and how they function. A key feature of the student-designed device is that it is easily adjustable so that students can see how changes in the link lengths have a profound effect on the motion of the mechanism. The VIP group not only designed the apparatus, but also developed a highly-effective exercise that could be completed in a 50-minute class period, and which combined aspects of design synthesis and analysis.

Figure 10: Students working with the Tabletopper experimental platform.

4. Survey Results

Pre and post surveys were done for the fall 2014 and for the spring 2015 offerings of the dynamics course, and a longitudinal study including a survey one semester after the semester ended was done for fall 2014 section of the course. Figure 11 displays the longitudinal results spanning the pre-survey, post-survey, and survey taken one semester later (marked as “post one term” in the plot) where N = 65. This particular set of questions asked students to rate their understanding of the basic course concepts listed, 1 = no understanding, 2 = minimal understanding, 3 = moderate understanding, and 4 = solid understanding. This survey essentially determines the confidence levels that students have in particular topics. The peak confidence is achieved in the post survey done at the end of the term. Note that the survey taken one semester later shows very little degradation from the confidence levels of the post survey, indicating a feeling of retention of knowledge of the material.

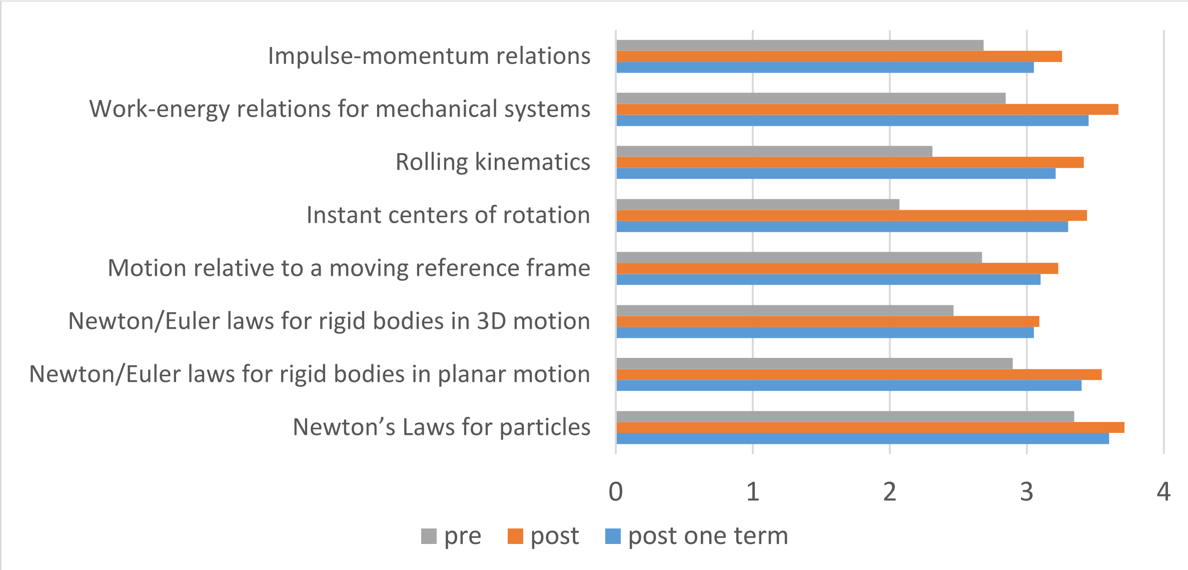

Figure 11: Survey indicating confidence levels of the students' understanding of the topics across a longitudinal study.

The post survey for both semesters asked students to indicate their level of agreement to the statement "Use of this course component was very helpful for me to learn the material in this course," with 1 = strongly disagree to 6 = strongly agree. Figure 12 shows the comparison between the semesters. Recall that the similarities between the terms include the content, the instructor, the format of the course; the worksheets, in-class quizzes, and homework were equivalent in number, style, and difficulty. The two main differences in the course in the spring offering were the experience level of the instructor in teaching a blended course (fall was his first experience) and the number and style of in-class experiments. The instructor received end-of-term teacher ratings of 4.9 and 5.0 out of 5.0 for the fall and spring terms, respectively, indicating that the experience level of teaching a blended class did not affect the students' attitude towards the overall course structure. While spring term ratings of delivery methods were higher in ten of eleven topics, the two most dramatic gains are in the use of experiments and instructor experimental demonstrations. Interestingly, the fall had two experiments and the spring only had one, yet the students in the spring felt much more strongly that it helped them learn the course material. Recall that the difference was that in the fall, the instructor did the experiments in front of the class and sent the data to the students for them to analyze using a worksheet. In the spring, the students did the same worksheet activities (performing calculations to predict the behavior and then comparing the predictions to the experimental results), but the students did the experiment themselves in the spring term (making it more hands-on). This difference in experimental delivery suggest that touch (doing the experiment themselves) rather than just sight (watching someone else do it) had a striking difference in students belief in the effectiveness of the experiments in helping them to learn the topics. The other instructor experimental demonstrations were the same in both terms, so it is believed that the hands-on experiment had a collateral effect on the students' appreciation of experiments.

Another aspect of Figure 12 is the ordering of preferences for delivery of course content. The traditional course delivery methods are the four at the top. This course blended these techniques with the other activities listed by reducing the amount of time doing in-class lectures. The result for spring semester showed a reasonably balanced appreciation of the different methods of course delivery.

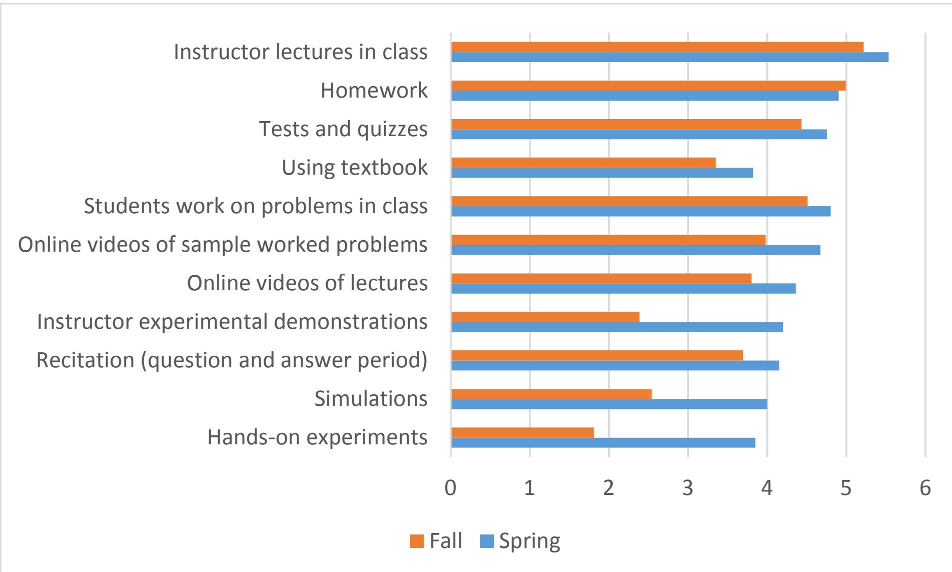

Figure 12: Comparison of post survey results from fall and spring terms showing the major difference in the students' belief that the experiments were useful in learning the material. N = 65 and 61, for Fall and Spring, respectively.

Students were also asked on the Spring 2015 post survey to rate the course delivery methods on whether they feel that the method would help them outside of the course. Specifically, they were asked to indicate their level of agreement to the statement "This course component gave me skills or knowledge that I feel will be very valuable to me outside of this course; for example, in subsequent courses, jobs, technical projects, extracurricular activities, etc." with 1 = strongly disagree to 6 = strongly agree. Thus while Figure 12 indicates what methods were most helpful in learning the course material, this question asks what would be most helpful in other circumstances. The results for both questions are compared in Figure 13. Students felt that most of the methods were equally or slightly less helpful for activities outside of this particular course. The only three exceptions were the experiments and the simulation, which showed a slightly increased belief that those methods would be useful in activities subsequent to the course.

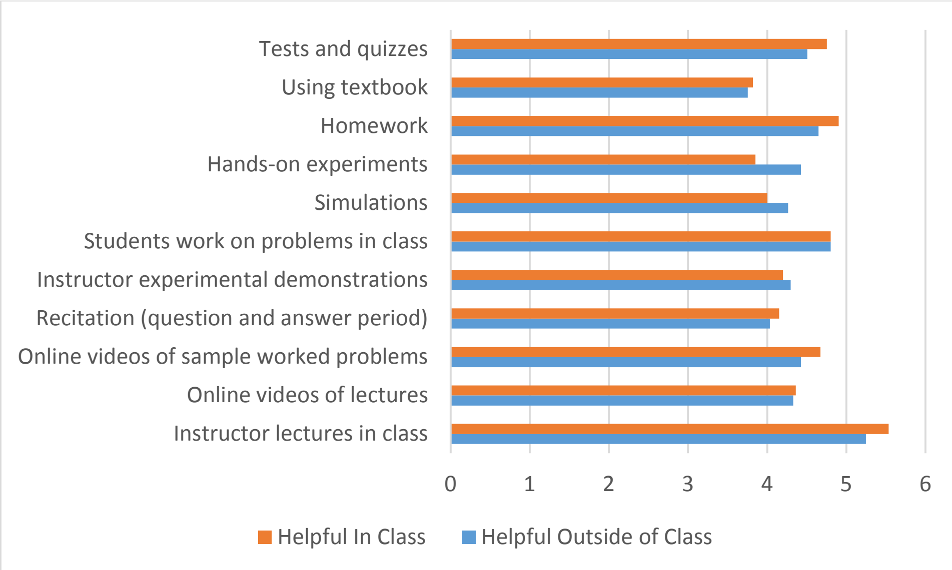

Figure 13: Spring post survey comparing the students' opinions on the helpfulness of different course delivery methods for the course itself and for activities outside of the course (work, co-curricular, subsequent courses). N = 61.

A question was asked specifically about the benefits of hands-on experiment. The statements in Figure 14 (for Spring 2015) were rated on a scale of 1=strongly disagree to 6=strongly agree. Though all categories rated between 4 and 5, the highest rated categories were on collaboration and on thinking of the problems graphically or pictorially. The answers to the open-ended free response question asking what they would change about the experiments were aggregated into common topics shown in Table 2.

A comparison of Table 1, corresponding to Fall 2014 where the professor demonstrated the experiments and sent the data to the students for analysis, to Table 2, corresponding to Spring 2015 where the students did the experiment themselves, shows a much more positive attitude towards the experiments in Spring 2015. Summarizing the results of Table 1 indicates that 84% of the responses suggested improvements to the way the experiments were used or conducted and the remaining 16% suggested that the experiments be eliminated. No one in Fall 2014 asked for more experiments. In contrast, 77.5% of the students in Spring 2015 (Table 2) asked for more hands-on experiments, while 12.5% suggested improvements and only 7.5% suggested that the experiments be eliminated. The open-ended responses in the Spring 2015 survey indicated that the students really liked the experiment, and this indicates that they appreciate the practical skills gained by doing the hands-on experiment.

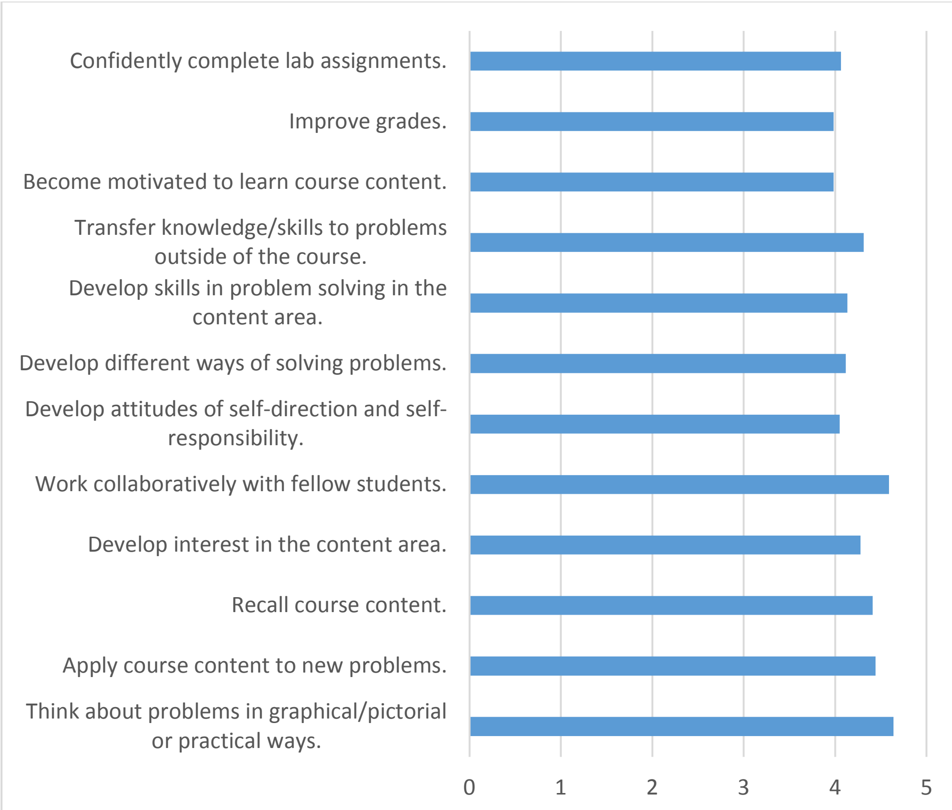

Figure 14: Spring post survey question indicating the students' ratings of the different benefits that the hands-on experiment had for them (N=61).

Table 2: Aggregated responses from open-ended question on "What would you change in the use of experiments in this class?" Spring 2015.

Issue	Times Mentioned
Have more hands-on experiments	31
Tie the experiments to theory better	4
Eliminate the experiments	3
Make them more applicable to real life or practical examples	2
Other	3

5. Conclusions

This paper describes the results from an educational study of course improvement carried out on an undergraduate dynamics course in mechanical engineering. The dynamics course was changed substantially to be delivered in a flipped/blended mode with lectures largely accomplished through video modules supplied by two Coursera MOOCs. This freed up in-class time for active and collaborative learning in the form of group work, worksheets, problem solving, and in-class experiments. In the Fall of 2014 and Spring of 2015, two different implementations were studied. In the Fall 2014 semester, the in-class lectures included two experimental demonstrations conducted by the instructor, with data analyzed by the students in class. The reception from students was largely positive, but a significant number of students expressed a desire to actually do the experiment themselves. Consequently, the Spring 2015 offering of the course used small, portable experiments that students tested using their own smartphones with an app to access their on-board accelerometers. Extensive survey results were conducted in Fall and Spring with results reported in the paper. One of the key findings is that students expressed a strong preference for experiments that they performed themselves, and felt that this helped them to learn the material better.

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