Impact of Classroom Demonstrations and Surveys on Higher-level Learning

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Abstract

An educational technique was developed to increase student learning of fundamental concepts in statics and particle dynamics. This technique consisted of online surveys on conceptual problems and a physical demonstration during class, and was implemented on four different concepts: particle equilibrium, couples, support reactions, and curvilinear motion of a particle. It was designed to test and improve students' ability to recognize concepts and then apply the concepts to different situations, in order to increase the students' learning level in Bloom's Taxonomy. Initially a pre-survey was given to the students and then the correct answer was illustrated with a physical demonstration. Afterward, a post-survey was given to the students on a more complicated problem to have students apply a given concept to a different problem. To observe the effectiveness of the demonstrations, one group of the students was exposed to the demonstrations and the other group was not exposed to the demonstration. The students' response on the surveys were compared between the two groups, which showed that three out of four demonstrations were overall helpful to the students in learning the concepts. The demonstration/surveys on particle equilibrium was the most effective one, followed by support reactions and couples. At the end of the semester, each group completed a feedback survey to rate how well the demonstrations and/or surveys helped their understanding of each concept. The feedback on demonstration/surveys from the group exposed to the demonstrations was more positive than the group who was not exposed to the demonstrations. We also found that the demonstrations combined with surveys were beneficial in creating more discussions among the students. In addition, the demonstrations were very useful for the instructors when they illustrated related topics to the students throughout the semester.

Introduction

Statics and particle dynamics is a sophomore-level course required by most engineering majors at universities. Compared to the introductory physics classes, where the focus is on concepts, a major element of these classes in the engineering context is on being able to bring multiple concepts together for making qualitative judgements. It is quite challenging for many students to relate what is covered in class to how bodies actually behave, especially if they do not understand concepts correctly. It is then essential for instructors to know what common misconceptions students have and how to correct them. Clement [1] studied different teaching strategies to deal with students' preconceptions in physics. He opined that curriculum developers should focus on students' anchoring concepts (prior knowledge which agrees with accepted theory) as much as on students' alternative conceptions (misconceptions), since their anchoring concepts provides a good starting point for instructions. Demonstrations offer students visual associations that they may capture and remember physical phenomena more effectively than verbal descriptions do [2]. Thus, demonstrations are useful to correct students' misconceptions and build their useful anchoring concepts which can be utilized when they learn more advanced concepts.

It has been shown by numerous studies that demonstrations play a very important role in science and engineering teaching [3, 4, 5, 6]. However, several researchers suggested that simply observing a demonstration may not effectively help students' learning of scientific concepts [7, 8]. Crouch et al. [9] and Milner et al. [10] showed that the effect of a demonstration on learning can be improved by increasing student engagement (through prediction and discussion) compared to passive observation of demonstrations. Also, Freedman et al. [11] extensively examined 225 studies on how student performance under active learning is different from that under traditional lecturing in undergraduate science, technology, engineering, and mathematics (STEM) courses. They found that active learning, through discussion and/or activities in class, is more advantageous than traditional lecturing in improving student performance across the STEM fields and across all class sizes. This aligns well with the need in the engineering mechanics classes to engage student in qualitative judgement activities for active learning.

Several studies have been conducted on demonstrations for engineering courses. Vander Schaaf and Klosky [12], Welch and Klosky [13] presented demonstrations for solid mechanics to link theory to the students' natural knowledge and excite interest in the course. Paul. S. Steif and Anna Dollár [14, 15, 16] developed demonstrations on statics along with concept questions that involved students applying forces with their hands or body to make force and moment concepts more perceivable in a tangible way.

Encouraged by these previous works, we have developed physical demonstrations combined with online surveys before and after the demonstrations. Our aim is to clear up common misconceptions that students have on statics and particle dynamics, and then to improve students' ability to utilize the corrected concepts to solve different problems. The pre-surveys and demonstrations allow students to connect what they learn to actual behaviors of bodies and also help students to build their anchoring concepts that can be used in understanding more complicated concepts. The post-surveys were designed to test and improve students' ability to go beyond identifying the concepts and to apply the concepts to more difficult situations, where the students' learning level can become higher in Bloom's Taxonomy. We emphasized surveying the students before and after the demonstrations with discussions to get students more actively involved in the demonstrations. Thus the demonstrations combined with surveys encouraged them to reflect on the concepts they were learning. Our survey questions were developed to improve conceptual thinking and qualitative judgment aspects of the topics versus calculation of values.

Instructors need to understand that students have different learning styles to facilitate their learning [17]. For example, some students prefer explanations of theory before exposed to practice and others respond well when practice is connected to theory. Thus, it is important for instructors to interrelate theory and practice to satisfy students with different learning styles. Our educational technique supports this aspect in that the concepts (theory) covered in lecture were related to practice through performing or observing the demonstrations. Conversely, the practice related to the concepts was connected through discussions after the demonstrations.

Our study is different from the previous researches on engineering courses [12, 13, 14, 15, 16] in that we used the survey results to measure the effectiveness of the demonstrations while they assessed their demonstrations by students' feedback. Since our pre- and post-surveys were oriented to test students' capability to identify the concepts and apply them to different problems, respectively, we used these surveys to measure how the demonstrations affected the students' application of concepts beyond identification of the concepts. Another key aspect of this work is that we focused our efforts on students in engineering majors (such as industrial, chemical, biological, agricultural, petroleum, nuclear, and so on) who do not have as much exposure to mechanical systems as mechanical engineering majors. The key difference between such majors and mechanical engineering majors is that for many of the students, there are no follow-on classes beyond the freshman physics mechanics course, so many of them take this statics class several semesters later.

Our technique was implemented in several class sections with approximately 400 total students. In the following sections, we describe our educational technique and report on the online surveys and physical demonstrations on four concepts: particle equilibrium, couples, support reactions, and curvilinear motion of a particle.

Description of the teaching technique

Our instructional technique incorporated physical demonstrations and online surveys before and after the demonstrations, which followed these steps:

1. The students were given an online pre-survey on basic conceptual questions in a multiple choice format and answered based on their knowledge and intuition.
2. The results of the pre-survey were presented and discussed to provide students with immediate feedback on the class responses.
3. A physical demonstration related to the pre-survey was performed where several students participated and reported their results to the class.
4. The students were given an online post-survey on more advanced problems in a multiple choice format.
5. The results of the post-survey were shown and discussed in class to give students feedback on the correct answers.

Our hypothesis is that demonstrations are more beneficial than mere descriptions in helping students understand certain core concepts of statics and particle dynamics. Before applying this technique to every student, we wanted to explore whether this hypothesis is true. If the demonstrations are found to be effective, we would like to employ this teaching technique to all students who take the statics and particle dynamics course in the future. To measure the effectiveness of a demonstration on student learning, different class sections were treated differently as in Fig. 1. Group1 completed the pre-survey, demonstration and post-survey, following the steps outlined above. Demonstrations were performed by several volunteer students under instructor supervision. It was found in previous semesters that the level of interest from the class was higher when students performed the demonstrations rather than the instructor. Group2 carried out the same pre-/post-survey without a demonstration part and worked on additional in-class problems after the post-surveys. The additional problems worked by Group2 illustrated the same learning concepts as the demonstrations for a more equitable experience as Group1. Each group consisted of two or three class sections. The students' response on the pre-/post-survey and their feedback on the demonstrations/surveys are compared between Group1 and Group2 for each topic and discussed to comment on the misconceptions that students had and the effect of demonstrations. Their responses on the surveys were also examined using a Bayesian A/B Testing approach to gain further insight into the efficacy of the demonstrations. The amount of time spent by the technique during class was 10 to 15 minutes for completing pre-/post-surveys and discussion, and additional 5 minutes for the demonstrations with discussion. So, overall 15 to 20 minutes were taken to carry out our educational experiment. For students in Group2 who did not see the demonstrations, an equivalent amount of time (5 minutes) was spent on working additional class problems on the topic. The number of students who participated were not the same for all topics and the number of participants for each topic are provided in the following sections.

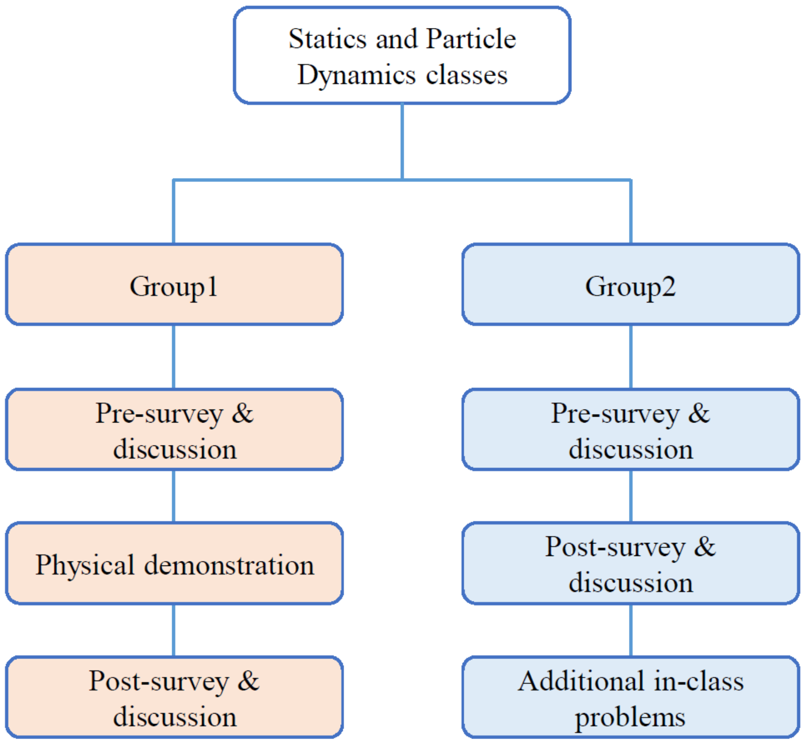


Figure 1. Structure of the teaching technique.

This combination of online surveys with demonstrations is one of the unique aspects of our technique. The surveys and discussion of those answers got most of the students in class engaged in the demonstration compared to the few students who actually participated in it. This increased interest in the demonstration was reflected by the numerous discussions and enthusiastic comments among the students. The second unique aspect of our study is the measurement of the effectiveness of the demonstrations by comparing the survey responses and students' opinion on the demonstrations/surveys between Group1 (with demonstration) and Group2 (without demonstration). Since the post-surveys consisted of problems that were more difficult than those in the pre-surveys, it allows us to see if the students' level of learning increased to a higher level in Bloom's Taxonomy, moving from a remembering level to an applying level. Thus, we attempted to measure whether the demonstrations are beneficial for students in utilizing key concepts of statics and particle dynamics in more difficult situations.

Particle equilibrium in two dimensions (2D)

One common concept that students have difficulty in understanding is the force equilibrium of a particle. The intent of this demonstration/surveys was for students to correct their concept on particle equilibrium in 2D and take this knowledge forward when evaluating trusses, for example, and having an idea of which members carry most of the load.

Q1. Which cable carries the most load?

Q2. If both ropes AB and AC have the same maximum load rating, which rope breaks first?

Q3. As the angle θ is increased, does the force in cable AB increase?

Q4. As the angle θ increases, does the force in cable AC increase?

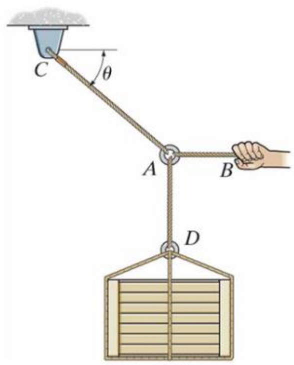


Figure 2. Pre-survey on particle equilibrium in 2D [18].

Figure 3. Demonstration tools on particle equilibrium in 2D (fish scales, chains and bag).

Q1. If ϕ increases, how does the load in the cable AC change (increase/decrease/stays the same)?

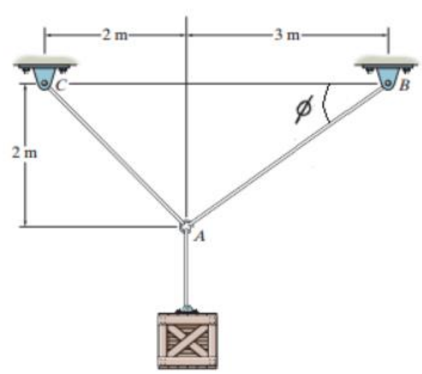


Figure 4. Post-survey on particle equilibrium in 2D [18].

The online pre-survey of Fig. 2 was taken by both Group1 and Group2, and they were asked which cable carries most of the weight and what happens to the forces in cable AB and cable AC if the angle θ is increased. To provide the students with feedback, the survey results were shown and discussed in class. The demonstration part was carried out only in Group1. The physical demonstration (Fig. 3) was on the same problem shown in the pre-survey which was simulated by two students each holding a fish scale that was connected to a suspended bag by chains. One student held a chain horizontal while the other student held a chain at an angle. They told the class what forces they read from the fish scales and how the forces in chains were affected by increasing and decreasing the angle θ. This physically illustrated the correct answers to the pre-survey. After the demonstration, a post-survey shown in Fig. 4 was conducted in both Group1 and 2 on a more advanced problem. It asked them how the load in cable AC changes as the angle ϕ increases. It was hoped, based on the pre-survey and demonstration, that the students would recognize the more vertical cable carries most of the load and increasing the angle results in a decrease in the load carried in the cables.

In the pre-survey, both Group1 and Group2 answered the first three questions mostly correct while half of each group answered the fourth question wrong. This shows that students tend to assume that increasing one variable makes the other variable decreased which is not the case in this problem. So, this misconception on Q4 was further questioned in the post-survey. Table 1 shows the percentage of correct responses of the students on the pre-survey's Q4 and the post-survey. After the demonstration that was performed in Group1, the percentage of students having correct answers in the post-survey indicated that both groups increased the ability to answer the quantitative judgement question. However, the improvement in Group1 was 19.3% while the improvement of Group2 is about 6.5%. This was the highest percentage improvement on the statics concepts we investigated. Therefore, the demonstration on the particle equilibrium in 2D was advantageous to the students in learning the concept.

Table 1. Percentage of students having correct answers in online surveys on particle equilibrium in 2D (Group1: 167 students, Group2: 194 students). Mapping: pre-survey's Q4 → post-survey.

		% of correct answer	
		Group1	**Group2**
Pre-survey	**Q4**	51.9	57.7
Demo		yes	no
Post-survey		71.2	64.2
Improvement ($\%_{post} - \%_{pre}$)		**19.3**	**6.5**

In order to study the significance of these results and gain further insight, we follow and adopt a Bayesian approach [19, 20]. Since we have two groups of students with different "treatments", we followed the standard Bayesian A/B test where the prior probability distribution given the measured success/failure ratio in the pre-survey is given by a beta distribution β (No. of prior successes + 1, number of prior failures +1) and the posterior is given by β (No. of post + prior successes + 1, number of post + prior failures + 1). With these in mind and using the standard Bayesian approach (it is a straightforward calculation based on a Monte Carlo sampling of 100,000 points from the appropriate distributions), we found that:

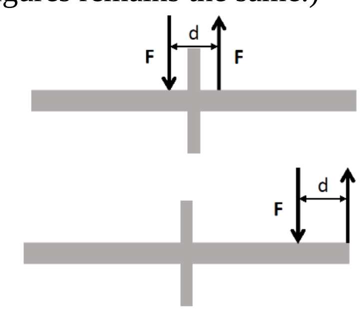
1. There is a 98% chance that the demonstration-based approach (discussion on pre-survey + demonstration) improved the students' ability with the average improvement being 19.3%.
2. There is a 77% chance that the discussion on the pre-survey improved the student ability with an average improvement of about 6.5%.
3. We can also state that there is an 84% chance that the students were improved by the demonstrations.

Couples in 2D

Understanding couples is one of the challenges in statics that students struggle with. Paul and Dollár [15] developed their own physical object to illustrate students the effect of couples. We constructed a similar object to carry out demonstrations in class.

Group1 and Group2 completed the pre-survey in Fig. 5 regarding the basic notions on couples. The questions address whether the location of a couple affects the motion of a body, and on the magnitude of a couple moment. The answers on the survey was discussed followed by a demonstration which was performed in Group1.

Q1. If the location of the forces acting on the beam is changed from top figure to bottom one, will this affect the motion of the beam? (The magnitude of the force F in both figures remains the same.)



Q2. If the distance between the forces is decreased while the magnitude of the rotation of the beam remains the same, will this affect the forces P_1?

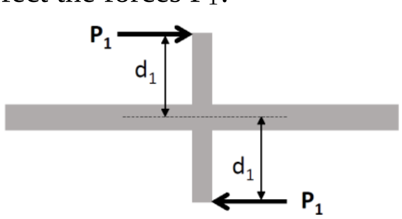
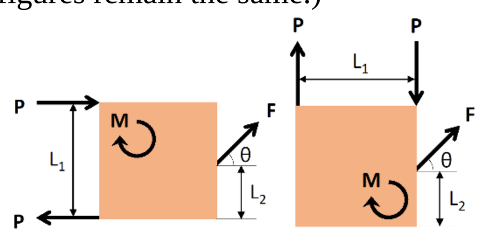


Figure 5. Pre-survey on couples in 2D.

Q1. If the locations of the forces P and couple moment M are changed from left figure to right one, will this affect the motion of the plate? (The magnitude of each force and couple moment in both figures remain the same.)



Q2. If the direction of the forces P acting on the plate is changed from left figure to right one, will this affect the magnitude of rotation of the plate? (The magnitude of each force and couple moment in both figures remain the same.)

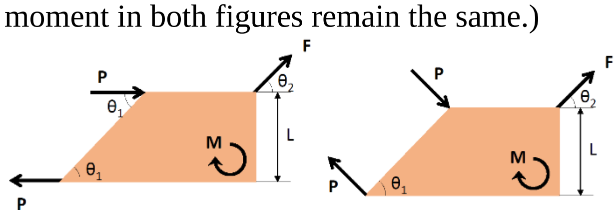


Figure 6. Post-survey on couples in 2D.

The demonstration was on the similar problems with the pre-survey. As in Fig. 7, one student applied a couple using the rubber bands connected to hooks of the beam (case A) and the other student created a couple with their fingers at the tips of the peg (case B). The motions of the beam were shown to the class using the document camera. Next the students applied two couples together to learn about the magnitude of a couple moment. For case C in Fig. 7, one student exerted a couple F and the other student exerted a couple P_1 at the tips of the peg until the beam was stationary in a horizontal position. Then, they performed case D; while the student applying a couple F kept his/her fingers at the same position, the other student put their fingers on the peg close to the center of the body and applied a couple P_2 until the beam was horizontal again. The student who applied a couple at different positions on the peg told the class in which case he/she applied a larger force to keep the beam horizontal.

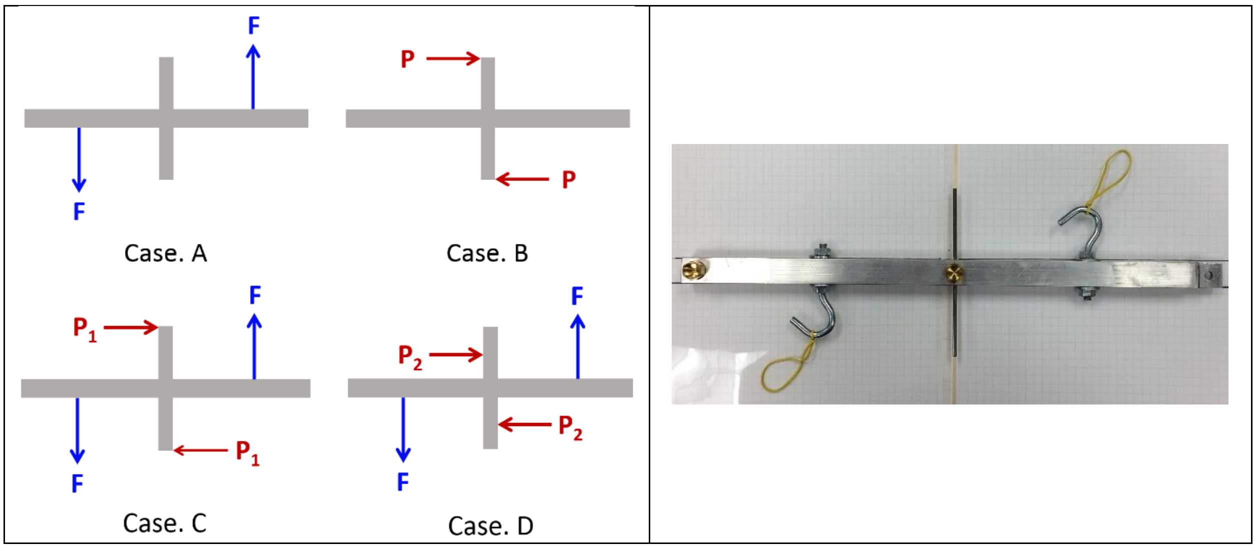


Figure 7. Demonstration on couples in 2D [15].

The post-survey was carried out by both Group1 and 2 on different shapes (Fig. 6). The first question which is similar to the pre-survey's Q1 asked students if the location of a couple and a couple moment affects the motion of a body. The concept of the moment arm of a couple was treated in the second question which asked the similar question with the pre-survey's Q2. The results of the post-survey were explained and discussed to give students feedback.

The students' response on the online surveys is presented in Table 2. The pre-survey's Q1 maps to post-survey's Q1 and the pre-survey's Q2 maps to post-survey's Q2. The response on Q1 of the pre-survey tells us that half of the students in each group think that the location of a couple influences the body motion. According to the response on Q2 of the pre-survey, half of the students in each group did not understand the magnitude of a couple moment. Both Group1 and 2 answered mostly correct on Q1 of the post-survey (Fig. 6) and the improvement of Group1 and Group2 in this concept was 31.6% and 21.7%, respectively. According to the response in the post-survey's Q2, half of each group still did not understand the effect of the moment arm of a couple. Group1 did not show any improvement and Group2 improved 3%. So, the demonstration was overall helpful in their learning the concept related to Q1 of the pre-/post-survey.

Table 2. Percentage of students having correct answers in online surveys on couples in 2D (Group1: 219 students, Group2: 185 students). Mapping: pre-survey's Q1 → post-survey's Q1, pre-survey's Q2 → post-survey's Q2.

		% of correct answer Group1	Group2
Pre-survey	**Q1**	49.8	61.1
	Q2	56.2	46.5
Demo		yes	no
Post-survey	**Q1**	81.4	82.8
	Q2	54.3	49.5
Improvement for Q1 ($\%_{post} - \%_{pre}$)		**31.6**	**21.7**
Improvement for Q2 ($\%_{post} - \%_{pre}$)		**-1.9**	**3.0**

On Question 1, the standard Bayesian approach (it is a straightforward calculation based on a Monte Carlo sampling of 100,000 points from the appropriate distributions) reveals that

1. There is a 99% chance that the demonstration-based approach (discussion on pre-survey + demonstration) improved the students' ability in Q1 with the average improvement being 31.6%.
2. There is a 99% chance that the discussion on pre-survey improved the student ability with an average improvement of about 21.7%.
3. We also observed that there is a 70% chance that there were improvements due to the demonstrations. This illustrates a key issue in the sense that both the approaches provided very large improvements, consequently there is comparatively little advantage in choosing one over the other although the demonstrations-based approach does retain a slight advantage.

On Question 2, the results are much more mixed:

1. There is only a 39% chance that the demonstration-based approach improved the students' ability in question (in other words, there is a 61% chance that the demonstration actually worsened the outcome to this question). The average loss was about 1.9 %.
2. There is a 65% chance that the discussion on the pre-survey improved the student ability with an average improvement of about 3%.
3. We also observed that there is 70% chance that the effect of the discussion on pre-survey with demonstrations was worse than that due to the discussion on pre-survey alone.

It was commented by Group1 that the document camera did not show the demonstration tool well to the class. It would be better to have more beam tools available so that more students could see or participate in the demonstration.

Support reactions in 2D

Another common misconception that students have is on the reactions which various supports provide. Students have difficulty in deciding when a force or a moment is exerted by the support on a body and thus what reactions should be included on a free body diagram (FBD).

The pre-survey (Fig. 8) questioned both Group1 and Group2 on choosing the correct FBD of a bar when it is connected to pin support and to a fixed support. Survey results were shown and discussed in class.

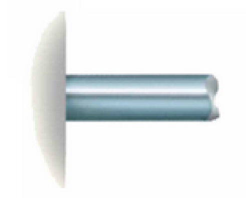
Q1. Choose the correct FBD of a bar for pin support:	Q2. Choose the correct FBD of a bar for fixed support:
	

Figure 8. Pre-survey on 2D support reactions [18]

The correct answers to the survey were illustrated with a demonstration (Fig. 9a-b) performed for Group1. Rulers were passed out to groups of students to share. A pin support was simulated by putting a pencil through a hole at one end of the ruler and holding it against the desk so that the pencil (pin support) would not move. The students exerted forces at different directions to the other end of the ruler as shown in Fig. 9a. It was discussed that the pin support could prevent translation but not rotation. For a fixed support, the students grabbed one end of the ruler and applied forces at different directions to the other end as in Fig. 9b. The students could perceive that the motions which their hand (fixed support) prevented were both translation and rotation. Through these demonstrations, students could feel both force and moment reactions that their hands must supply to the ruler for equilibrium.

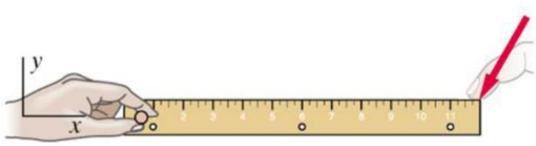
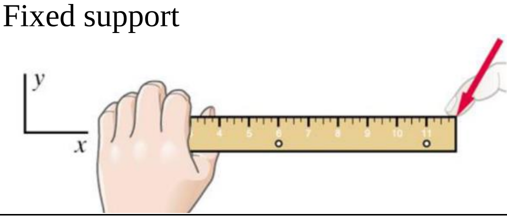
1. Pin support	2. Fixed support
	

Figure 9a. Demonstration problems on 2D support reactions [21]

Figure 9b. Demonstration tools on 2D support reactions (ruler with a hole, pencil)

Post-surveys were completed by both Group1 and 2. The questions were more advanced than the pre-survey questions and are typical of supports that students in past semesters have trouble with. A roller and a collar on a smooth rod were given as in Fig. 10 and the students were asked to select the correct FBD from multiple choices.

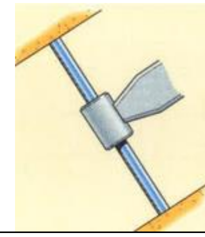
Q1. Choose the correct FBD of a bar for roller: 	Q2. Choose the correct FBD of a bar for collar on smooth rod: 

Figure 10. Post-survey on 2D support reactions [18]

Table 3 shows the percentage of the students who answered correctly in pre-/post-survey for both groups. In the pre-survey, more than half of the students in both groups chose the correct FBD for a pin support and less than half chose the correct FBD for a fixed support. For the post-survey, more students of each group chose a correct FBD for roller support than the collar on a smooth rod. It seems that the number of the reactions by a support and the complexity in geometry of the support affect the difficulty of these problems for the students. After performing the demonstration, Group1 improved 12.4% for Q1 and 11.7% for Q2 in correct responses while Group2 improved 6.1% for Q1 and 4.9% for Q2. The support reactions illustrated by simply using rulers helped Group1 improve their learning of 2D support reactions.

Table 3. Percentage of students having correct answers in online surveys on 2D support reactions (Group1: 217 students, Group2: 175 students).

		% of correct answer	
		Group1	**Group2**
Pre-survey	**Q1**	55.8	57.1
	Q2	46.5	47.4
Demo		yes	no
Post-survey	**Q1**	68.2	63.2
	Q2	58.2	52.3
Improvement for Q1 ($\%_{post} - \%_{pre}$)		**12.4**	**6.1**
Improvement for Q2 ($\%_{post} - \%_{pre}$)		**11.7**	**4.9**

Here, the Bayesian approach reveals the followings:
For Question 1,

1. There is a 93% chance that the demonstration combined with discussion on pre-survey improved outcomes with the average improvement being 12.4%.
2. There is an 80% chance that the discussion on pre-survey improved outcomes with the average improvement being 6.1%.
3. There is a 65% chance that the demonstration improved the outcome.

For Question 2,

1. There is a 93% chance that the demonstration with discussion on pre-survey improved outcomes with the average improvement being 11.7%.
2. There is a 17% chance that the discussion on pre-survey improved outcomes with the average improvement being 4.9%.

3. There is a 75% chance that the demonstration was effective at improving the outcome.

Curvilinear motion of a particle

Students have a hard time in dynamics when choosing the correct radius of rotation in curvilinear motion of a particle. The following surveys and demonstration were intended to effectively illustrate curvilinear motion of a particle to students.

Group1 and 2 took the pre-survey given in Fig. 11 which questioned them about the acceleration of a sphere and the radius of rotation of a sphere. After the pre-survey results were explained to the students, the demonstration was conducted in Group1 on the similar problem with the pre-survey. The problem was simulated by the hoop shown in Fig. 12. There was a small ball inside the circular hoop which was spun by a drill at variable speeds. One student adjusted the drill speed such that the ball was located at an angle $\phi = 70°$ and the other student counted the number of rotation of the hoop in a given time period. The class then computed the angular velocity when $\phi = 70°$. The students also observed how the angle of the ball was changed by increasing and decreasing the drill speed. The angular velocities when the angle ϕ is lower and higher than 70° were also computed and compared by the class. The demonstration was followed by the post-survey which was carried out in both Group1 and 2. The post-survey problem in Fig. 13 was on the same concept with the pre-survey. It asked them on the radius of the rotation of the passenger which will be used in computing the acceleration. The answers for the survey problems were shown to the students, and the instructors and the class discussed the radius of the circular path of the body and the body's acceleration in polar coordinates.

A small sphere slides on a circular hoop. Friction between the sphere and hoop is negligible. The hoop is rotated at a constant angular velocity ω and the sphere locates to a constant angle $\phi = 45°$.

Q1. If you use polar coordinates to describe the acceleration of the sphere, what will the acceleration vector look like when you "adapt" it to this problem?

Q2. What is the value of r that you will use in the acceleration equation for the sphere (which ultimately goes into Newton's 2nd law)?

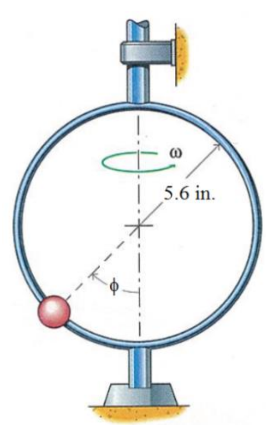


Figure 11. Pre-survey on curvilinear motion of a particle [22].

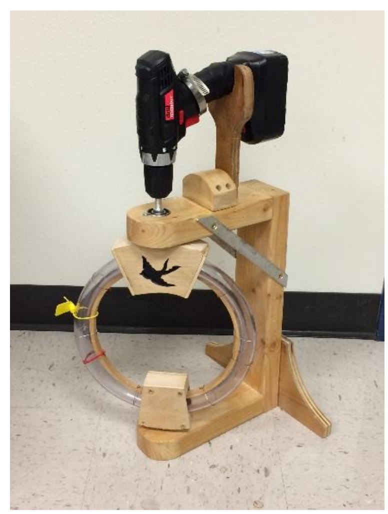


Figure 12. Demonstration tool on curvilinear motion of a particle.

The four passengers on the amusement-park ride are rotating with constant speed when ϕ=30°. Each chair including its passenger has a mass of 80kg.

Q1. What is the value of r that you will use in the acceleration equation for each chair including its passenger (which ultimately goes into Newton's 2nd law)?

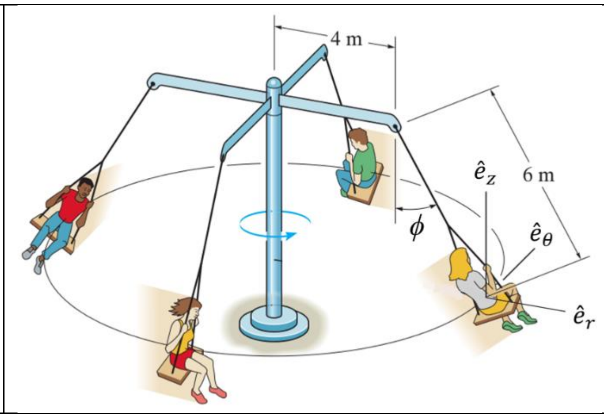


Figure 13. Post-survey on curvilinear motion of particle [18].

The percentage of correct response on the surveys are presented in Table 4. The students' response on the pre-survey shows that most of them did not have the right concept on the acceleration in polar coordinates when the angular velocity and the radius of rotation of a body are constant. Also, it was not clear to them what the radius of circular path of a body is which will be used when computing the acceleration in the equation of motion. In the post-survey, both groups were improved in their response on the radius of a circular path of a body when comparing with the response of the pre-survey. However, the improvement of Group1 was lower than Group2. The class gave comments that the ball inside the hoop was hard to recognize for the students who were seated in the back of the class room. This might be one of the reasons why the demonstration did not improve survey responses. If the visibility problem is resolved, the demonstration might be improved to give more benefits to students in learning the concepts on the curvilinear motion.

Table 4. Percentage of students having correct answers in online surveys on curvilinear motion (Group1: 114 students, Group2: 105 students). Mapping: pre-survey's Q1-2 → post-survey's Q1.

		% of correct answer	
		Group1	**Group2**
Pre-survey	**Q1**	30.5	36.2
	Q2	35.6	31.4
Demo		yes	no
Post-survey	**Q1**	56.9	67.9
Average improvement ($\%_{post} - \%_{pre}$)		**23.8**	**34.1**

The Bayesian approach reveals that:

1. There is a 99% chance that the demonstration-based approach (discussion on pre-survey + demonstration) improved outcomes with the average improvement being 23.8%.
2. There is an 80% chance that the discussion on the pre-survey improved outcomes with the average improvement being 34.1%.
3. There is a 63% chance that the discussion on the pre-survey were better at improving the outcome than the demonstration-based approach.

Feedback from the students and other comments

We also compared exam scores between the students in both Group1 and Group2 and found similar class averages. The exams were graded by the same person using the same rubric. It appears the demonstrations did not have a measureable effect on the student's performance on exams. Thus at the end of the semester we polled the students in each group on how the demonstration and surveys helped their learning of each topic. The students rated each topic on a Likert scale, from strongly agree (4) to strongly disagree (0), and Table 5 summarizes their feedback. Overall, the students in Group1 who were exposed to both demonstrations and surveys had higher satisfaction ratings than the students in Group2. Only the rating on couples is lower in Group1 than in Group2, which might be related to the visibility of the demonstration beam tool. Group1 also gave comments that the curvilinear motion hoop was not visible to the students in the back of the classroom. Thus, the visibility issue might be the reason why the demonstrations on couples and curvilinear motion had the lowest ratings.

Table 5. Students' feedback on demonstration and surveys on each topic (Group1: 69 students, Group2: 76 students).

As a student, "I feel like the demonstration and surveys helped my learning of the concepts illustrated."	**Average rating (out of 4)**	
	Group1	**Group2**
Particle equilibrium in 2D	3.17	2.96
Couples in 2D	2.80	2.95
Support reactions in 2D	3.05	2.87
Curvilinear motion of a particle	2.62	2.57

From an instructor viewpoint, it was noticed that the classroom atmosphere in Group1 was more positive than Group2, considering their comments and discussion increased during the demonstrations and post-survey results. The students in Group1 were more actively engaged in learning these concepts. An additional benefit for the instructors was the ability to refer back to the demonstrations when teaching related topics to the students throughout the semester.

Summary

We have developed physical demonstrations combined with online surveys during class time to illustrate four different fundamental concepts in statics and dynamics that many students have a hard time understanding. The goal of our technique was to increase the students' ability to recognize the concepts and then apply them to different problems. To see how the demonstrations helped the students in identifying and applying the related concepts, different class sections were treated differently as summarized in Fig. 1. The percentages of students having correct response in the surveys for each topic were compared between Group1 and Group2. Also, the feedback from the students in both groups on each demonstration/surveys were reported.

According to our experiments on the statics topics, the demonstrations with discussion on the surveys were slightly more efficacious in the students' learning of the concepts than giving discussions on the surveys only. However, the efficacy of demonstration for couples was not uniform. For the dynamics concept on curvilinear motion, the demonstration did not add anything to students' learning. This might be because the dynamics problem was harder to visualize compared to statics problems. Overall, Group1 who was exposed to the demonstrations showed better improvement compared to Group2 who was not exposed to the demonstrations. We speculate that this is because the demonstrations provided the students with visual associations that helped the students remember the concepts effectively and apply the concepts to different situations.

We expected to find more improvement in survey results from the students who participated in the demonstrations than what is shown in Table 1-4. We attribute some of the poorer results to the post-survey questions which were confusing to the students. These questions are being revised for use in our statics and dynamics courses in subsequent semesters. According to the students' feedback on the demonstrations/surveys, Group1 had higher ratings indicating that the demonstrations/surveys with discussion were beneficial to their learning. Even Group2 felt the surveys with discussion were helpful to learning the concepts. The demonstrations on couples and curvilinear motion had the lowest ratings due to the poor visibility. These demonstrations need to be revised to avoid the visibility issue.

The most worthwhile demonstration/surveys was on particle equilibrium in 2D, followed by support reactions in 2D and couples in 2D. Several demonstrations and survey questions are being improved for use in future classes due to results from this study. Eventually we hope to show more definitive improvement for learning of these concepts.

Comparing the classroom atmosphere between the two groups, the physical demonstrations had an important role in encouraging more discussions among the students. It was also found that the demonstrations were very advantageous for the instructors when explaining related topics to the students throughout the semester.

This technique of demonstration and pre-/post-surveys with discussion of different statics and dynamics topics were overall helpful to both students and instructors. They served to engage the class and promote learning of concepts that many students struggle with. We feel this educational technique has been especially helpful to the students in other engineering majors who are not as familiar with mechanical systems as mechanical engineering majors.

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