What Works in Teaching Engineering Statics

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Dr. Jim Shih-Jiun Chen is a professor of mechanical engineering at Temple University. His research and teaching interests are in the areas of fluid mechanics, heat transfer, and wind energy. He has published more than 100 articles in fluid flow, temperature measurement and control, film cooling, jet impingement, accelerated/controlled cooling, melt spinning, and wind energy. In education, he has advised students winning national and international competitions in designing energy efficient systems. Dr. Chen received the Distinguished Faculty Award from the College of Engineering at Temple University in 1996. He has been a member of ASME since 1986. Since Fall 2007, he has taught over 300 students in ten (10) sections of Engineering Statics.

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Alani Intintolo was a junior in the mechanical engineer program when she worked as a Diamond Peer Teacher (DPT) during the Spring 2011 semester. She once considered changing her major to secondary education. This DPT program fulfills her wish to be both an engineer and a teacher. She has helped many students in the Engineering Statics class and has made some friends. She is now a senior at Temple University.

What Works in Teaching Engineering Statics

Abstract

Engineering Statics is a critical fundamental course for subsequent mechanics courses such as Engineering Dynamics, Solid Mechanics, Fluid Mechanics, etc in various disciplines in engineering. After teaching ten (10) sections of Engineering Statics since Fall 2007, the lead author summarizes and illustrates what works in teaching Statics to more than 300 students. Traditional methods of lectures, homework assignments, and exams only work for top, motivated students in the class. Most students, who grow up in the digital age, prefer approaches involving real senses of touch (hands-on) and sight (graphs and demonstrations). Active learning along with teamwork also contributes to a good learning practice.

The Diamond Peer Teacher (DPT) Program was experimented for the first time in Engineering Statics during the Spring 2011 semester. The program provides upper-level undergraduates at Temple the opportunity to experience the challenges and rewards of college-level teaching, to develop their own pedagogical skills by working closely with their faculty mentors, and to provide supplemental instruction in lower-level courses. The DPT had a GPA over 3.5 and received an A in Engineering Statics last year. When the student performance of two (2) sections were compared, section 1 without and section 2 with the peer teacher, the average exam scores were identical during the first exam, but the average scores were higher by 10 percentage points in section two during the final exam. This paper discusses how the DPT enhances active learning and promotes study groups. Excerpts from the final report by the DPT are also included.

Keywords: Hands-on, study group, teamwork, Diamond Peer Teacher.

Introduction

Engineering Statics is a critical fundamental course for subsequent mechanics courses such as Engineering Dynamics, Solid Mechanics, Fluid Mechanics, etc in various disciplines in engineering. The prerequisites of Engineering Statics are Calculus I and Physics I and the corequisite is Calculus II. The lead author has taken the leading role of teaching Engineering Statics since 2007. Over 300 students from various engineering programs including Civil Engineering, Environmental Engineering, Electrical Engineering, and Mechanical Engineering have enrolled in the ten (10) sections taught by the lead author.

In accordance with the ABET 2000 guidelines [1], the syllabus clearly states five Course Learning Objectives (CLOs) as:
1. Utilize Free-body Diagrams to apply concepts of equilibrium to particles or rigid bodies. (PO A)
2. Analyze forces and moments in two and three dimensions, using calculus and vector analysis. (PO A, E, n)
3. Utilize concepts of centroids and moments of inertia (PO n)

4. Analyze structures including trusses, frames and machines (PO A, E, n)
5. Understand friction and its application (PO A, E, n)

The corresponding Program Outcomes or Student Outcomes are:
A. Ability to apply current knowledge and applications of mathematics, science, engineering and technology.
E. Ability to identify, formulate, analyze and solve technical and engineering problems.
n. Knowledge of chemistry, or biology, and calculus-based physics.
Traditional methods of lectures, homework assignments, and exams only work for mature and motivated students in the class. Yet, most instructors still adopt the old generation's study-anddrill approach, which is outdated and ineffective for long term learning. Today's students grow up in the digital age, and prefer approaches involving real senses of touch (hands-on) and sight (graphs and demonstrations). Steif and Dollar [4] proposed that senses of sight and touch improve the students' comprehension of forces and moments in Statics. They have developed learning modules which involve collaboratively manipulating objects and responding to conceptual questions. A newly published book [2] offers information on the most effective ways that students process information; store it in their long-term memories, and how that affects learning for long-term retention. It provides a handy introduction to the 'why and how' of engaging students in the STEM (Science, Technology, Engineering, and Mathematics) disciplines in the learning process. Among various methods contributing to good learning practice described in the book, teamwork and active learning have been effectively adopted by the lead author in Engineering Statics instructions at Temple University. A new Diamond Peer Teacher Program, developed at Temple University enhances active learning and teamwork.

The aims of this paper are (1) to show how hands-on experience and visual demonstration help students to construct FBDs and apply force and moment principles, and (2) to demonstrate the effectiveness of active learning and teamwork, which is further enhanced by Temple's Diamond Peer Teacher Program.

Construction of Free-Body Diagrams

If the students have adequate knowledge of trigonometry, calculus and vector algebra, the single most important concept in Engineering Statics is the construction of free body diagrams of rigid bodies. First, common types of force application on mechanical systems for analysis are introduced. Types of contact and force origin to be modeled include cables, rods, beams, smooth surfaces, rough surfaces, roller support, freely sliding guide, pin connection, fixed support, weight, and spring in two dimensions, Three dimensional modeling and analysis are introduced and discussed, but most homework and exam problems are two dimensional. Detailed step-bystep procedures for constructing FBDs and for solving problems are given in [2]. Students are told to read these thoroughly and follow the steps closely in doing homework assignments and group quizzes in the class.

Sketching FBDs on the blackboard is the most widely used method for teaching students how to isolate a system and draw a FBD. Key steps of constructing FBDs for problem solving include: (1) identify clearly the known and unknown quantities, (2) isolate a system by choosing a single body, a section of a rigid body, or a system of connecting bodies, drawing its complete FBD, (2) identify the external boundary and label all known and unknown quantities (forces and moments), (3) choose a convenient set of references axes and moment center for equilibrium force and moment equations, (4) match the number of independent equations with the number of unknowns in each problem, usually three each for two-dimensional problems, and (5) carry out the solutions and check the results with additional equations or alternative methods.

Hands-On and Visual Demonstration

Many students struggled with the selection and construction of FBDs and the identification of known and unknown forces and moments. After showing numerous examples, the authors found that most students had a much better understanding when students are engaged in hands-on and/or sight experience when the instructor explains the force and moment principles. As shown in Fig, 1(a), this demonstration was borrowed from an exhibit in Philadelphia's Franklin Institute. The instructor asked every student in the class to stand up and balance his/her body with one foot.
After a while, every student found a balance by shifting his/her weight to above the foot. They also found that the one-foot stand was unstable as shown in Fig, 1(b), when the CG is slightly shifted, a moment would cause the body to lose balance. A balancing bird was then demonstrated to show its unconditional stability. A restoring moment (couple) is produced as a result of CG below the center of support where the finger tip meets the bird's beak tip. Figure 2 is another demonstration of force and moment principles from the Franklin Institute.

Figure 3(a) shows a person pulling a door with a pulling force P. All external forces (in red) are identified and shown in the correct directions. The three unknowns are P, A_x, and A_y, which can be solved using the two force equations and one moment equation. Most students choose point A to be the moment center so as to simplify calculations, but a different center can be used to check the solutions. When Fig. 3(b) is compared with Fig. 3(a), two differences are identified>. First, the hands are pushing instead of pulling so that the force is in the opposite direction. Second, the two feet in Fig. 3(b) are spread so that the person is statically indeterminate to gain

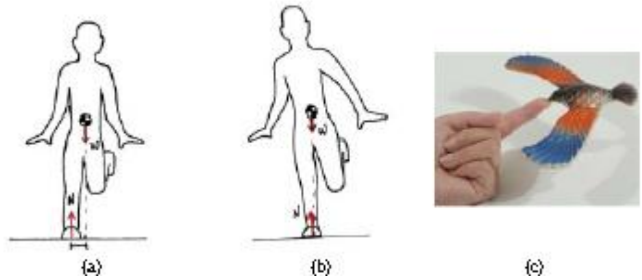

Fig. 1 (a) A person standing on one foot is unstable because of a clockwise moment (couple) is produced by the distance between the two equal but opposite forces, (b) the person becomes conditionally stable by shifting the center of gravity (CG) to above the foot to satisfy Σ**F** = 0 and Σ*M* = 0; however, case (b) becomes unstable if the CG is slightly shifted to left or right, (c) to maintain unconditional stability, CG must be below the center of support, as shown by the selfbalancing bird.

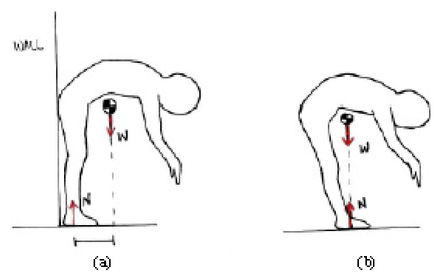

Fig. 2 (a) A person with his back and feet against the wall cannot bend down his body because a clockwise moment is produced by the distance between the two equal but opposite forces, (b) when the person moves away from the wall and shifts the center of gravity (CG) backward to right above the feet, the body becomes conditionally stable because the equilibrium equations of Σ***F*** = 0 and Σ*M* = 0 are satisfied.

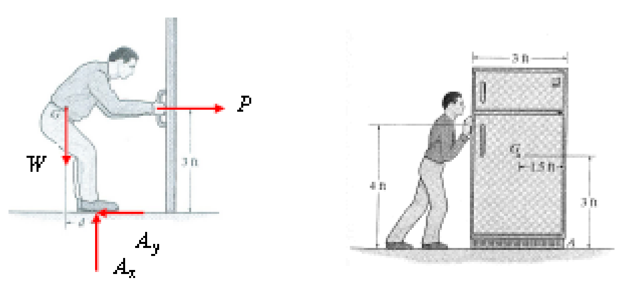

Fig. 3 (a) A person pulling the door with two feet together is stable and statically determinate, (b) a person pushing the refrigerator with two feet apart is stable and statically indeterminate, i.e., the rigid body has excessive fixity or redundancy.

more stability. The extra supports constitute redundancy which is preferred in the real world. Students were told that the analysis and design of structures and systems with redundancy will be discussed in upper level courses.
Figure 4 shows a person pushing the wall horizontally. After constructing the FBD, the problem can be solved with 3 unknowns (B_x, A_x, A_y) with the three independent force and moment equations. An alternative method can be used by considering that three forces in equilibrium must be concurrent (at point *O*) and must form a force triangle. The unknown force components can be solved using the simple trigonometric functions. As the pushing force *B* increases, the friction at *A* must also increase by moving the feet farther away from the wall.
Figure 5 shows how a careful choice of the reference axes and a FBD can simplify the analysis. First, choosing the x axis along the inclined surface and y-axis normal to the inclined surface simplifies the force components when normal and frictional forces are considered. Second, a FBD of the person with two feet separated shows that this body is statically indeterminate. Therefore, a FBD of the lawn mower indicating the three unknown force components N_B, N_C, and *P* should be used for the two-dimensional problem. The three unknown forces can be solved using two force equations (in the x and y directions) plus one moment equation or two moment equations (about moment centers *B* and *C)* plus one force (normal to the inclined surface) equation can be used [3].

As shown in Fig. 6(a), trusses were demonstrated to the students using the K'nex joints and rods. Fig. 6(b) shows that the four bars pin-jointed to form a square is collapsible. By adding a cross bar to the square, students quickly learned that the triangle element is rigid. Therefore, the basic element of a plane truss is the triangle and various simple trusses can be built by adding two member bars (*m*) for each joint (*j*) added. For any plane truss, the equation of a plane truss, $m = 2j - 3$ is satisfied is the plane truss is statically determinate internally. To simply the analysis, each member is assumed to be a two-force (tension or compression) member and each joint is assumed to be a pin joint so that it is free to rotate.

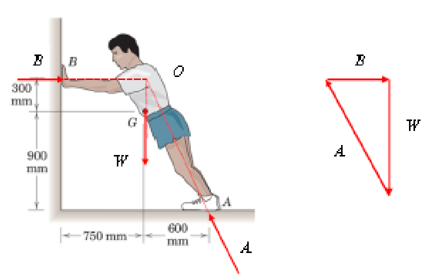

Fig. 4 A person pushing the wall horizontally is stable with three forces being concurrent at point *O* so that $\Sigma M_o = 0$ and forming a force triangle so that $\Sigma \boldsymbol{F} = 0$. The person is statically determinate if the friction between the hands and the wall is negligible.

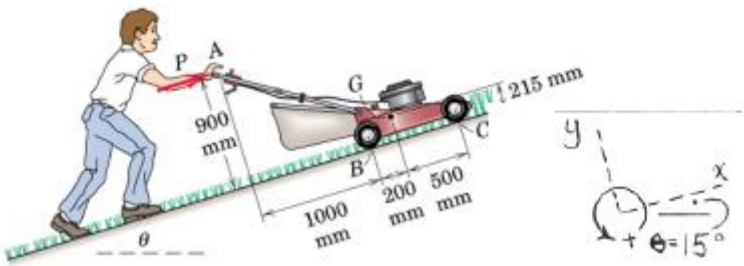

Fig. 5 Careful choices of the reference axes and FBD simplify the analysis [3].

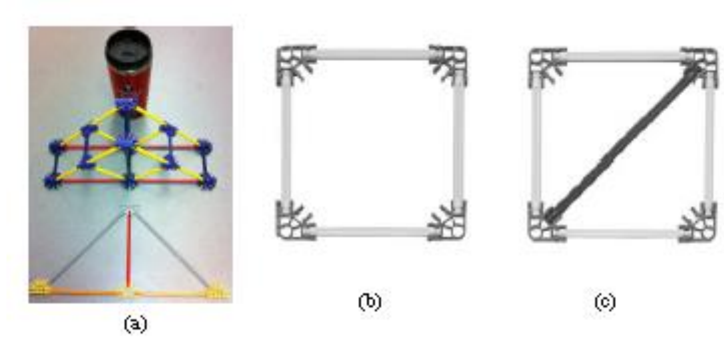

Figure 6 Hands-on with K'nex trusses: (a) simple plane trusses, (b) collapsible structure, (c) rigid structure.

Active Learning and Teamwork

During the first week of each semester, every student was asked to fill out a data sheet, which should include the contact information of two other classmates. Students were then encouraged to form study groups in and outside the classroom. To promote teamwork, pop quizzes lasting 15-20 minutes were given biweekly to teams of three (3 students forming a triangle) in the class with the assistance of the Diamond Peer Teacher, whose function will be elaborated in the next section. A group of 4-8 students often studied together one hour before the class or during the lunch time. They either found an empty classroom where they can teach each other using the blackboard or they worked in the lounge area as shown in Fig. 7.

Figure 7 A study group of 4-8 students before the class and during lunch time.

Diamond Peer Teacher (DPT)

The Diamond Peer Teacher Program was experimented for the first time in Engineering Statics during Spring 2011. The program provides upper-level undergraduates at Temple the opportunity to experience the challenges and rewards of college-level teaching, to develop their own pedagogical skills by working closely with their faculty mentors, and to provide supplemental instruction in lower-level courses. The peer teacher must have a cumulative GPA 3.25 with 60 credit hours by end of the semester in which they are applying. In addition, the peer teacher must have earned at least an A- in the course (or equivalent) for which they are applying to be a Peer Teacher. Program requirements include (1) attending an all-day Peer Teaching Institute workshop, (2) committing 12-15 hours per week during the semester to attend the class in which they are a Peer Teacher; to provide regularly scheduled tutoring / class contact for students in the class (one-two hours for every hour of class); to keep two hours of "office hours" per week to meet individually with students; to attend weekly meetings with their Faculty mentor; to attend scheduled meetings with other Peer Teachers, (3) submitting a mid-term selfassessment, and (4) submitting a final report / self assessment on their experience at the end of the semester.

Excerpts of the final report (as part of a one-credit course: Peer Teacher Internship) are given below.

Program Purpose:
"This program fulfilled both of its primary goals – experience on my part and education on the part of the student successfully. I have found that some of the most pivotal turning points in my understandings of course concepts have not been due to the teacher, but due to the teachings from a classmate who describe things in a different but enlightening way. My mentor and I stressed the concept of contacts and study groups. As the semester wore on, I began to notice many people in the class making connections and working in groups when applicable. This was more evident to me in terms of office hours, where the caliber of questions asked seemed to increase in difficult towards the end of the semester suggesting that students were now using

their formed networks to ask more-challenging questions. I was fortunate enough to have students utilize my office hours and I do believe that they were beneficial. There was also a very high turnout at nearly all of the recitation sessions I taught in which I often tried to stress trickier concepts and work through problems. The test average from the first exam to the second exam increased by 20% (from 60/100 to 73/100), which was fantastic news and verifies my feelings that these services were beneficial. After providing a list of students tutored after the first exam, I was given feedback verifying the increase in grades from the first to second exam for those students. Each student showed improvement, with the largest grade increase being 36%!"

Tell a Friend
"I am now more prepared for a Teaching Assistant position if I choose to apply for one during my graduate studies. If I had a friend who also wanted an introduction to teaching but did not have a loose schedule in regards to workload and time, I would definitely suggest that they apply for a position within their respective college. I would also suggest this program to a classmate if she had helped me learn a class previously; I believe that the ability to teach a friend difficult concepts without making them feel inferior is one of the best skills to have for this program. A positive attitude is also a must. The most satisfaction I received from this program was when I could recognize that a student having difficulties finally shifted from having the ability to solve one specific problem to gaining the ability to solve any problem of containing those concepts. This happened most during study hours, where after letting a student work through a problem and bringing to attention certain mistakes, they could later work through an entire problem without a hitch. When this occurred, I felt assured that a student understood a concept as well as accomplishment as a Peer Teacher."

The Struggle
"Unfortunately, there are also less positive experiences when trying to teach, especially an entire group of students with different needs and different levels of dedication. At one point during a recitation section I had to assert myself more than normally to regain the attention of a particular group of students. In my opinion, they were being disrespectful to the classroom setting; however, from my own experiences I know that I have done the same at times, and these instances were not malicious and not even intentional, so I did not read more into the situation than was necessary. Other times students would make comments that hinted at their desire for the easiest option or minimal effort on their own parts, but this just fueled me to ask more of them.
At the end of the day (or in a following recitation), these "negative" experiences seemed to boost respect and class response! If one is quick to temper or easily frustrated, I would not recommend that he apply for a position as a Diamond Peer Teacher. To those that want to give back in the learning experience, help others reach academic success, and challenge their own abilities while retaining the ability to maintain a positive outlook: apply to be a DTP!"
Comments from students as well as suggestions for future DPTs regarding what to do (e.g., explaining what each problem-solving step is and why it is being taken) and what not to do (e.g., solving homework problems for students) are summarized in Appendix B. **Results of Teamwork and DPT**

Table 1 lists how four (4) students performed in major exams during the Spring 2011 semester.

One might have guessed that Student 4 was the team leader, pictured in Fig. 7, who improved his own learning by leading the group study and by teaching the weaker students (Student 1 and Student 2) in the group. Student 1 and Student 2 improved their grades from very poor showing in Exam 1 to final grades of B- and C, respectively. Student 3 failed the course last year and did much better this time around. He attributed to his progress to the study group which met 2-3 times a week, usually during the lunch time and sometimes just after the class. Student turned to be Mr. Joseph Stoney, who has received the award to become a DPT for Engineering Statics in the Spring 2012 semester.

Table 1. An Exemplified Study Group's Exam Scores (out of 100, with DPT, Spring 2011)

	Exam 1	Exam 2	Final Exam	Final Grade
Student 1	30	79	89	B-
Student 2	44	69	78	C
Student 3	75	81	90	B+
Student 4	80	100	92	A

Direct assessment of student performance based on major exams is summarized in Table 1. Over 300 students have enrolled in 10 sections of Engineering Statics taught by the lead author since 2007. Students have improved by 15-20 percentage points from the pretest (10 multiple –choice questions of Math and Physics) to the posttest with the same 10 questions. After the student direct assessment between the four (4) sections with recitations (one hour weekly) by TAs and the other four (4) sections without recitations (usually evening classes) were compared, no difference was found in the student progress and performance. The average class size is 30-36 from Fall 2007 to Fall 2010. However, when the student performance of two (2) sections were compared in Spring 2011, section 1 without and section 2 with the DPT, the average exam scores were identical during the first exam, but the average scores were higher by 10 percentage points in section two for the final exam. This suggests that the effect of DPT was not significant after 5 weeks, but the presence of DPT became more and more beneficial in the last two thirds of the semester. What did we learn? Patience is a virtue and a DPT is more effective than a TA.

Table 2. Student Exam Scores (out of 100) in Section 1 (36 students, without DPT) and Section 2 (38 students, with DPT)

	Pretest	Exam 1	Exam 2	Posttest	Final Exam
Section 1	63	63	N/A	85	64
Section 2	64	60	73	85	74

Pass the Baton

The DPT wrote in her report: “Everyone learns differently, and as the semester passed, the diversity of learning became clear. Some students learn best by teaching, as was clearly the case for one particular member of the class. It was great to see someone take command of his education while being such a high influence on others – he (Mr. Joseph Stoney, pictured in Fig. 7) would make a great candidate for this program!” The student (Mr. Stoney) happily responded by applying to the DPT program and he wrote: “In Engineering Statics during the Spring 2011 semester approximately 8 students including myself studied together throughout the semester. I quickly grasped the concepts and theory of our topic and was very helpful to others. I set up study sessions for exams and utilized empty classrooms and 6th floor lounge to provide examples for the entire study group. It quickly became routine to come in an hour early for class and hold a student recitation for the early arrivals before lecture began. I enjoyed helping other students and have now been seeking out any opportunity to help others understand any topic we are working on. I look forward to helping others throughout my time at Temple University through the Diamond Peer Teaching program.” Just before this paper is finalized, Mr. Joseph Stoney has received a Diamond Peer Teacher award for Engineering Statics in Spring 2010. It appears that the DPT baton has been passed.

Summary

By requiring the prerequisites and giving students a pretest, students’ basic knowledge of Mathematics and Physics was reinforced. Instructions with visual demonstrations (sense of sight) improve students’ comprehension of FBDs and problem solving techniques. Hands-on experiences (sense of touch) with the balancing bird and K’nex trusses as well real-world examples (each student did the balancing acts of standing, bending, pushing, pulling) improve the student’s ability to apply force and moment principles to solve Engineering Statics problems.

Schematics of FBDs enhance the student to analyze a single rigid body or a system of components by selecting convenient references axes and moment centers. By investigating how forces and moments affect a structure or design, students can come up with a new design and thus demonstrates their synthesis skills. The success of learning Engineering Statics can be measured in Bloom’s Taxonomy, from Knowledge and Comprehension, to Application and Analysis, and finally to Synthesis, as summarized in Appendix A. Since this is a sophomore course, students have not developed the highest form of learning – Evaluation by judging a new design. Students are expected to grasp the “Evaluation” skill through upper level engineering courses.

The Diamond Peer Teacher Program is a highly beneficial program to both the student and the peer teacher. The Peer Teacher gains experience, insight, and leadership skills. The student is benefitted by more pathways of learning and a friendly connection for help that falls somewhere between the levels of peer and superior. However, this program is not for anybody. This program is for those special individuals who care about

helping others to learn and succeed and who have patience and skills to work with the diversity of Temple student body. We wholeheartedly hope and expect that the DPT program will succeed and continue in the future.
The success strongly depends on class teamwork emphasized by both the instructor and the DPT.

References:

1. ABET Student Outcomes, http://www.foundationcoalition.org/home/keycomponents/assessment_eval/ ec_outcomes_summaries.html
2. Mastascusa, E. J., Snyder, W. J., & Hoyt, B. S. (2011), Effective Instruction for STEM Disciplines: From Learning Theory to College Teaching, Jossey-Bass, A Wiley Imprint.
3. Meriam, J. L. & Kraige. L.G. (2010), Engineering Mechanics – Statics, 6th Edition, Wiley.
4. Steif, P.S. & Dollar, A. (2005), “Reinventing the Teaching of Statics,” Int. J. Engrg. Ed., Vol.
4, pp. 723-329, Templus Publication.

Appendix A. Bloom's Taxonomy used in Engineering Statics

Category	Example and Key Words (verbs)
Knowledge: Recall data or information.	Examples: Recite the laws of sines and cosines. Quote the 1^{st} and 3^{rd} Newton's laws of motion. Recall dot product and cross product.
Comprehension: Understand the meaning and interpretation of instructions and problems.	Examples: Rewrite the principles of transmissibility and concurrent forces. State a problem in one's own words with sketches.
Application: Apply what was learned in the classroom into surrounding real-world problems.	Examples: Apply principles of forces and moments to determine unknown quantities for equilibrium of particles and rigid bodies.
Analysis: Separate a system into component parts. Determine what principles to apply. Distinguish between facts and interferences.	Examples: Lear how to construct FBDs* by considering a single body, a section of a rigid body, and a system of connected rigid bodies. Select reference axes and moment centers.
Synthesis: Build a structure or machine from diverse elements, with emphasis on new ideas.	Examples: Design a new machine or a new process to perform a specific task so as to gain a mechanical advantage or stability.
Evaluation: Make judgments about the value of ideas or materials. Explain and justify a new design.	Examples: Select the most effective solution by examining alternatives. This should be implemented in upper level courses.

FBDs*: Free Body Diagrams.

Appendix B. Student Feedback and Comments on DPT:

What aspects of the course or the instructor's approach contributed most to your learning?

-"The instructor explained the problems in recitation very clearly which broadened understanding for the material."
-"Always chose good examples."
-"Easily accessible and approachable."
-"She always came well prepared for class."
-"Gave in-depth examples, made sure people's questions were answered and clear."

What aspects of the course or the instructor's approach would you change to improve the learning that takes place in the course?

-"I guess her only flaws would be that sometimes she assumed we knew certain concepts."

-“I am a believer that instructors of any level should be confident and in some ways controlled. Alani was good with the material, and would be great again, and hopefully she has learned to control the classroom environment a little more.”
-“More interactive classroom.”
-“Not just give equations; derive them so we understand where the equation came from.”
-“She should be more thorough, explain slowly and more carefully.”

What works in recitation?
-Give examples to show the techniques learned in class. The professor teaches the concepts; the peer teacher reinforces those concepts and shows them in action.
-Explain and show that (in most cases) there is not one correct approach to a statics problem, but multiple approaches and techniques that can be used to find the answer.
-Explain what each problem-solving step is and why it is being taken.
-Engage the students by encouraging them to lead you through the process. Ask them questions on what the next steps should be and why a step was taken keeps students attentive to the problem.

What does not work in recitation?
-Work on homework problems: It is helpful to work on similar concepts that students must be able to execute for their assignments, but working out real homework problems for students often leads to an inability on the students’ behalves to do their work independently.
-Allow students to talk outside of conversations related to solving the problem.
-Spend the majority of time on one student’s questions: if there is a student struggling to understand a concept and this is taking too much of the class’ recitation time, the peer teacher should suggest a separate tutoring session to address those issues so that everyone can benefit from the recitation.