Just a Moment – Classroom Demonstrations for Statics and Solid Mechanics

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Abstract

Engineers, faculty, and administrators in higher education understand that introductory solid mechanics courses such as Statics remain an essential component in most engineering curricula. Undergraduate students also recognize the importance of mastering mechanics courses. However, their enthusiasm is often curbed by their frustration trying to understand many of the critical, but often abstract, topics presented in the course. Compounded by large class sizes, reduced attention spans, and a heavy workload in other first-year courses, students can quickly feel overwhelmed and become disengaged from the course. That disinterest can eventually lead to an aversion to the entire engineering discipline. As expected, the turnover rate of first-year engineering programs can be substantial.

Statics instructors are then faced with a seemingly impossible task – effectively teach Statics and simultaneously engage students to grasp their attention to minimize attrition. It is well established that an effective way to accomplish this task is to maintain a high level of intellectual excitement by using active classroom demonstrations that engage students, enabling them to overcome boredom and frustration.

The objective of this study was to create a series of effective and fun classroom demonstrations (modules) to aid students in developing their conceptual understanding of *moments*, a fundamental topic in Statics. The motivation for this effort stemmed from anecdotal evidence in the form of student feedback and observations made during exam grading by the authors. The evidence suggested that students deemed moments to be one of the most challenging topics in Statics. Since the concept of moment is a recurring theme found throughout the hierarchy of mechanics courses, the authors created an active demonstration for each Statics subtopic involving moments. They include:

1. "At arm's length" – identify the principles of moments and moment arms using a volunteer's shoulder as a pivot point

2. "Students forming couples" – visualize the concept of a couple moment using two student volunteers applying equal and opposite forces to a rotating table

3. "Show some restraint" – identify the types of reactions found in typical support conditions used in engineering

4. "Cutting the cheese beam" – demonstrate the concept of generating a bending moment in an elastic beam due to an applied shear force

5. "Breaking bread" – demonstrate the difference between bending moment, and positive and negative shear in a beam using individual slices of bread as differential elements

6. "The MVP mnemonic" – illustrate a method for students to learn the sign convention for bending moment (*M*), shear force (*V*), and axial force (*P*) in beams

Each module includes objectives, an overview of the theory, resources needed, a step-by-step procedure, estimated preparation and demonstration times, as well as recommendations based upon the authors' experience. Cognizant of the time and budget constraints of faculty, the authors designed the modules to minimize the preparation time and cost associated to produce the demonstration materials.

Assessment consists of an Institutional Review Board (IRB) approved survey to solicit students' perception of the effectiveness of the demonstrations to improve their understanding of the statics concepts. The statistically significant results indicate the demonstrations were effective compared to a control group taught without them.

<u>Keywords</u>

Statics, mechanics, demonstration, assessment

1. Introduction

Introductory mechanics courses such as Statics are essential in engineering curricula. Statics includes a broad range of topics from vector mechanics to basic structural analysis. A thorough knowledge and mastery of Statics is essential for students to perform well in subsequent courses that build onto the fundamental concepts introduced in Statics.

It is well known that undergraduates enrolled in engineering programs often struggle with Statics. Numerous reasons are cited [1] to explain students' subpar performance. A substantial portion of the student body may either withdraw or fail the course; some may eventually transfer out of engineering altogether. It is not surprising that the retention rate of undergraduate engineering programs can be adversely affected. As a result, a Statics instructor may face substantial pressure (whether real or perceived) to minimize the attrition rate yet still prepare students for subsequent higher-level engineering coursework.

Various pedagogical approaches to teaching mechanics have been attempted with the intent of improving student success. Some approaches include supplemental instruction [2], interactive tutoring [3], recitations [4], virtual laboratories [5], online courseware [6], and gaming [7]. It is important to concede that even the most well-intentioned and passionate instructors may not have access to the resources to implement these unique approaches. Thus, traditional classroom instruction still remains the staple of the delivery method.

For junior faculty or even the most seasoned instructors, it can be challenging to maintain students' attention and simultaneously teach the increasingly challenging Statics concepts in an effective manner. However, as emphasized by Vander Schaaf et al. [8], maintaining intellectual excitement via classroom demonstrations enables students to overcome boredom and frustration when learning mechanics. It has also been shown that learning and retention can be improved by engaging students and generating excitement by utilizing hands-on learning methods, namely, demonstrations and physical manipulatives [9]-[11].

The conceptualization of a new physical demonstration is often followed by a Newtonian approach of trial-and-error. The instructor presents it during class and gauges the students' interest based on non-verbal cues. Continuous refinement of the demonstration to improve its effectiveness is then based on direct student feedback and quantitative assessment of student knowledge using an examination or other means. Though seemingly simple, the development and implementation of classroom demonstrations are not infallible. Most instructors prefer simple, inexpensive, yet effective demonstrations that can be carried out in class that are engaging and convey the principles of Statics. They must build onto students' prior knowledge so it's important to prompt students to recall their knowledge of topics covered in prior physics courses.

In this paper, the authors present several novel classroom demonstrations (modules) that have been implemented in a Statics course to improve students' understanding of *moment*. The four variations of moment include: a moment induced by a force about a specified point, a couple moment, an external moment reaction, and an internal bending moment in a structural member. Each module includes a step-by-step procedure and specific recommendations from the authors based on their experiences. Results from assessment/evaluations are included, as well as overall recommendations for the development of future demonstrations.

2. Study Context

2.1 Background

Moment is defined as an influence of a force to produce rotation about an axis. In equation form, the moment of a force about an axis passing through an assumed point *A* is:

$$|M_A| = |F\ d_\perp| \tag{1}$$

F is the magnitude of the force and $d_\perp$ (called the *moment arm*) is the perpendicular distance from the line of action of the force to the assumed point or axis of rotation. Equation (1) represents the mathematical basis for all statics topics that are moment-based, namely, couple moments, equivalent systems, static equilibrium with non-concurrent forces, and bending moment in beams.

Based on the authors' experience and observations over the past decade, students have difficulty understanding the concept of a moment. They easily grasp the concept of a force (such as weight, friction, and tension in a rope), but moment is a relatively abstract concept to them. Additional frustration is encountered due to the term "moment" since it conflicts with the students' prior knowledge from their physics course. There, they encountered the concept of *momentum*. This prior knowledge often leads to two misconceptions:

1. Since *momentum* is formed from the root "moment" with the addition of a derivational morpheme (*-um*), students assume that the concept of momentum presented in Physics is the same as the concept of moment in Physics.

2. The term moment has different meanings: (a) brief period of time, or (b) effect produced by a force acting at a distance on an object. Since "moment" is homographic and students have solely associated the word moment with a period of time, they assume that moment (in the context of a statics course) has a temporal component.

These may seem like trivial misconceptions, but the instructor should explicitly discuss and refute them prior to beginning any discussion or demonstrations related to moments.

2.2 Audience and Setting

Statics courses are geared towards 2^{nd} and 3^{rd} semester undergraduate students enrolled in a diverse group of engineering majors:

- Aerospace
- Architectural
- Biomedical
- Civil
- Environmental
- Industrial
- Mechanical

Pre-requisites includes one course in calculus and one course in calculus-based physics that includes mechanics through gravity and harmonic motion. Therefore, it is expected that students already have some knowledge of torque prior to taking Statics.

All of the demonstrations are carried out in a classroom with a maximum capacity of 40 students. Since the class sizes are relatively small (typically between 10 and 34 students), small classrooms can be utilized in lieu of lecture halls or auditoriums. Such large venues may not be appropriate for these demonstrations since the students may not be able to visualize them. All calculations are performed on a whiteboard.

2.3 Summary of Demonstrations

Table 1. Summary of Statics demonstrations

No.	Title of Demonstration	Objective
1	At Arm's Length	Identify the principles of moments using a volunteer's shoulder subjected to varying intensities of moment
2	Students Forming Couples	Visualize the effect of a couple moment formed by two volunteers applying equal and opposite forces to a table
3	Show Some Restraint	Show and compare the reactions from mock-ups of typical support conditions used in engineering
4	Cutting the Cheese Beam	Generate an internal bending moment in a cheese beam due to applied shear
5	Breaking Bread	Visualize and distinguish the difference in sign convention for internal shear in a sliced loaf of bread
6	The MVP Mnemonic	Introduce a memory technique to memorize the sign convention for internal forces and moment in a beam

In the section that follows, six demonstrations (Table 1) are presented along with an overview of the theory, resources needed, a step-by-step procedure, estimated preparation and demonstration times, as well as recommendations based upon the authors' experience.

The selection of a colloquial title for each demonstration is deliberate, as it is intended to generate student interest. All of the classroom demonstrations are initially performed using scalar computations. Their vector counterparts are introduced in successive lectures.

3. Statics Demonstrations

Demonstration #1: At Arm's Length

Overview: Students can easily relate to the concept of forces based upon their experiential knowledge. More specifically, students can readily identify forces that they *feel* acting on their own body. Demonstration #1 leverages that knowledge by exerting a moment that they can *feel*. A volunteer holds a weighted briefcase in his/her hand while the arm is extended from his/her side at varying positions. Moment arms and the corresponding moment magnitudes are computed for students to compare.

Student Learning Outcomes: capacity to: understand the basic principle of a moment, identify a moment arm, and compute the magnitude of a moment

Resources: Bookbag or briefcase weighing 5 to 10 lbs, tape measure, calculator

Preparation time: 2 minutes

Demonstration time: 15 minutes

Procedure: A volunteer stands at the front of the classroom facing the student audience. The instructor asks the volunteer to hold a briefcase in their right hand. In this first scenario (Case 1), the volunteer's arm is lowered to a vertical position, and as close to their body as possible; refer to Figure 1(a).

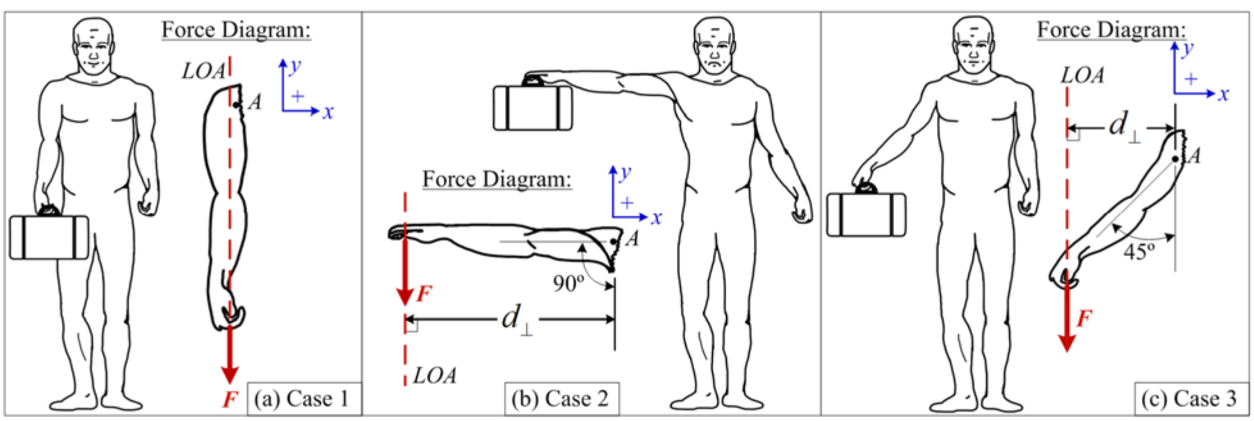


Figure 1. Arm positions and corresponding force diagrams for Demonstration #1

A force diagram of the volunteer's arm is drawn showing the force, F, which represents the weight of the briefcase. The weight of the arm is neglected to simplify the demonstration. The angle between the arm and the body should be approximately 0º such that the line of the action (*LOA*) of the force passes through an assumed point of rotation at the top of the arm, *A*. The volunteer is then asked to assess their level of ease in supporting the briefcase in the current position using a scale of 0 to 5 (0 = difficult; 5 = easy). The volunteer will likely respond with either 4 or 5.

In Case 2, the volunteer is asked to raise their arm to the horizontal position shown in Figure 1(b). Their level of ease should decrease significantly, likely to either 0 or 1. The class is asked to determine why the volunteer is experiencing difficulty and possibly feeling discomfort near the point of rotation, *A*. Since the bag's weight has not changed from Case 1 to 2, the students will inevitably conclude that the effect is due to the separation between the *LOA* of the force, and the point of rotation. The instructor denotes this effect as a *moment*, and the fundamental moment equation is introduced, namely, $|M_A| = |F\ d_{\perp}|$.

The horizontal length of the volunteer's arm is serendipitously equal to the *moment arm* ($d_{\perp}$), which is measured using the tape measure. When conducting the measurement, the bounds of the measurement should be stated, namely, between an assumed point of rotation on the top of the shoulder as well as the assumed point where the *LOA* of the force passes through the hand. Emphasis is placed on the fact that the moment arm must be perpendicular to the *LOA* of the force, as this necessity is often overlooked by students. The magnitude of the moment is then computed and the units of moment are presented. Using a 5-pound bag and assuming the volunteer's arm is 24 inches, the magnitude of the moment is 120 lb-in.

Case 3 involves rotating the volunteer's arm downward to about 45º, as shown in Figure 1(c). The volunteer's level of ease should increase to about 2 or 3, and he/she should clearly feel that the moment has been reduced. The moment is computed again, though the instructor should emphasize that the moment arm is no longer equal to the length of the volunteer's arm. The moment magnitude should be about 85 lb-in.

Case 1 is now revisited to compute the moment when the volunteer's arm was vertical. Students should realize that, since the moment arm is so small (assumed zero), a moment was not created. This is an ideal opportunity for the instructor to point out that a moment does not exist when the *LOA* of a force passes through the point of rotation.

The moments from all three cases are summarized, along with the volunteer's ratings. Students should acknowledge the correlation between moment and moment arm, namely, the magnitude of each moment (and corresponding shoulder discomfort) increased as the separation (between the force's *LOA* and the rotation point) increased. Comparing the moment magnitudes also allows students to gain a practical understanding of their relative intensities. For example, if the moment on the shoulder is 120 lb-in in Case 2, students should realize that 2000 lb-in is beyond the capability of a human to support.

Additional cases could also be demonstrated. Similar to Case 1, the student can hold the bag with their arm extended vertically, but raised upwards. Again, the moment should be approximately zero. Another case can demonstrate superposition of moments by including the weight of the volunteer's arm or, alternatively, having a second volunteer apply an upward force on the first volunteer's arm to create a counteracting moment on the shoulder.

Recommendations: Based upon their experience, the authors offer several recommendations:

1. Inform the volunteer of the overall procedure and obtain their verbal consent before performing the demonstration.
2. The concept of moment direction (rotation about the *z*-axis) and distinguishing between positive and negative moment can commence after the last case is presented.
3. It is safer to utilize a flexible cloth tape measure in lieu of a traditional metal one (with a blade and hook) since the latter could injure the volunteer if he/she should turn their head while the instructor is taking measurements near the shoulder.

Demonstration #2: Students Forming Couples

Overview: This activity demonstrates the concept of a couple moment using two volunteers applying equal and opposite forces to a table. The magnitude and direction of the moment are computed, and the concept of equivalent systems is also introduced.

Student Learning Outcomes: ability to: recognize a couple moment, predict rigid body motion under the action of a couple moment, and compute the magnitude of a couple moment

Resources: Table, tape measure, two 0.5"-diameter ropes (each at least 1' longer than the longest side length of the table), calculator, and dynamometer [optional]

Preparation time: 5 minutes

Demonstration time: 10 minutes

Procedure: It is assumed that lectures prior to this demonstration have sufficiently covered pre-requisite topics, including the moment vector, summation of moments, and the Right-Hand Rule. In the session when Demonstration #2 will be performed, students should first be provided with a formal definition of a *couple moment*, namely, the effect from the action of a pair of forces of equal magnitude applied on a body in parallel, but opposite, directions and separated by a distance.

Two volunteers stand on opposite sides of a table facing the student audience. Each volunteer ties one rope to the leg on opposite ends of a table (Figure 2).

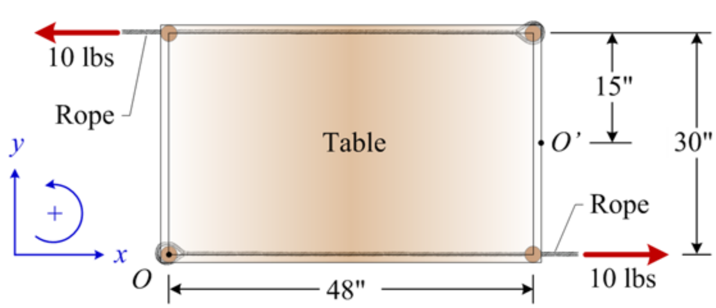


Figure 2. Plan view of table with parallel forces applied via ropes

Prior to the pulling by volunteers, a force diagram is drawn of the table top (plan view) showing the *x*-forces; friction forces beneath the table legs are assumed to be equal and opposite and, thus, cancel. Equilibrium equations $(\Sigma F_x = 0, \Sigma F_y = 0, \Sigma M_O \neq 0)$ are written to reach the obvious conclusion that all forces balance in both directions, thus, translational acceleration is not expected. Since rotational equilibrium is not satisfied $(\Sigma M_O = 300 \text{ in-lb})$, students are prompted to predict the rigid body motion. The volunteers apply forces to the ropes to inevitably cause the table to rotate counterclockwise due to the couple moment.

Summation of moments is revisited by using another point on the table (such as *O′* in Figure 2). $\Sigma M_{O'} = 300 \text{ in-lb}$ is identical to the previous result using *O* as the basis for the moment computation. Students should realize that, when dealing with a couple moment, the reference point for moment summation is irrelevant. Thus, the preferred equation for computing a couple moment is:

$$M_{Couple} = \pm F \; d_{\perp} \tag{2}$$

The direction (±) is assigned using the Right-Hand Rule, *F* is the magnitude of either force, and $d_{\perp}$ is the perpendicular distance between the forces. Since the resultant force is zero and the net effect is purely rotational, the instructor can introduce the standard symbol to represent a couple moment in a two-dimensional drawing as well as the three-dimensional vector representation. These are shown in Figure 3(a) and Figure 3(b), respectively.

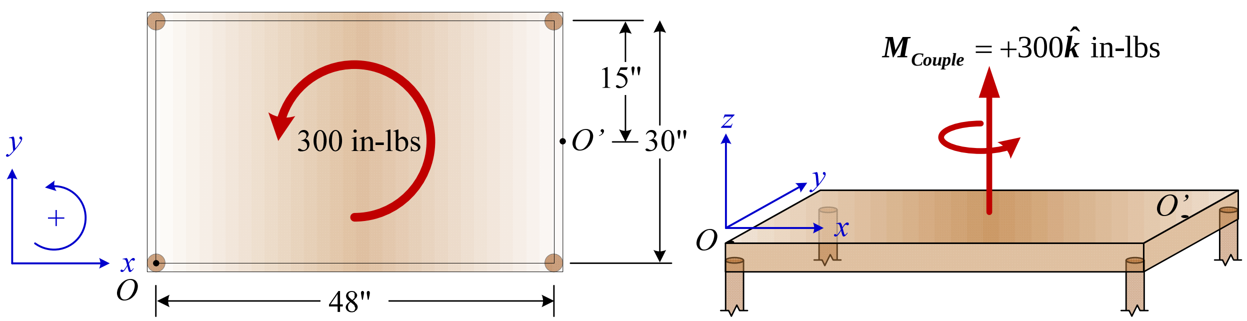


Figure 3. Couple moment representations

The concept of equivalent systems can be introduced at this point by asking students to consider an equivalent couple moment formed by another pair of equal forces, but pointing in the *y*-direction.

<u>Recommendations</u>: Unless a dynamometer is available to measure the tensile force in each rope, an approximate value of 10 lbs serves as a reasonable estimate that also facilitates simpler moment computations during the demonstration.

Demonstration #3: Show Some Restraints

Overview: This demonstration presents idealized support models that are commonly encountered in engineering mechanics and subsequent coursework in the civil and mechanical engineering disciplines. Although considerable preparation time is initially necessary to build the support mock-ups, they can be used for many years with little to no maintenance.

Student Learning Outcomes: ability to: recognize each fundamental type of support (pin, roller, and fixed), and identify the scalar reaction(s) imparted to a body due to the support

Resources: 1" diameter PVC pipe, various pieces of wood, assortment of bolts and screws, demonstration table

Preparation time: > 4 hours

Demonstration time: 10 minutes

Procedure: Prior to the classroom demonstration, the various supports are designed and constructed using a variety of materials and assembly methods. Figure 4 presents a typical pin support, while Figure 5 is a roller support created by adding PVC pipes beneath the roller to permit translation. Figure 6 is a constrained pin, slot, or slider. Figure 7 displays two types of fixed or built-in supports, namely, a rigid beam-column joint and a vertical dowel-type joint using a wooden bar.

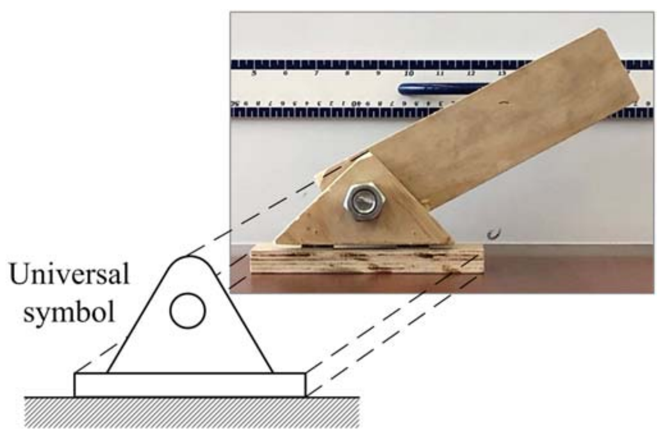


Figure 4. Pin support and universal symbol

Figure 5. Roller support and universal symbol

Figure 6. Constrained pin, slot, or slider, and universal symbol

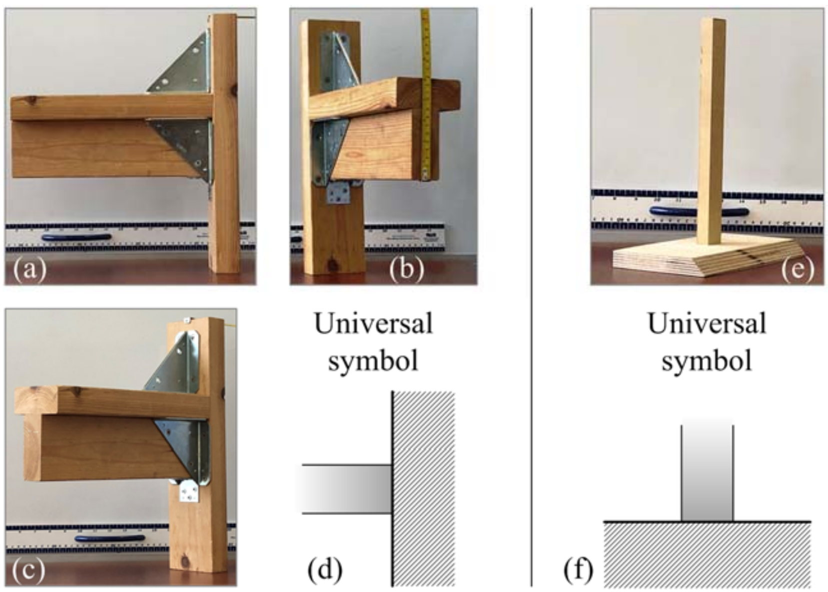
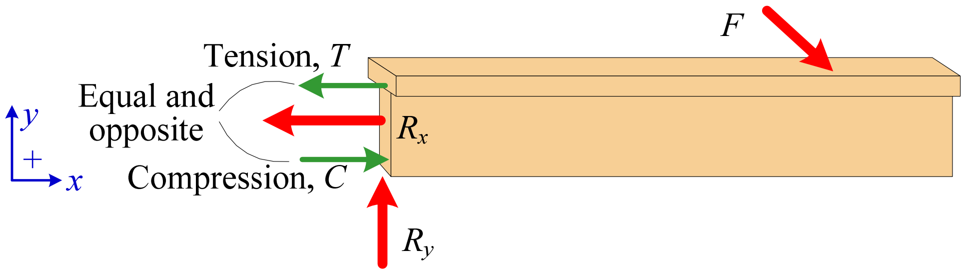


Figure 7. Fixed supports: (a) – (d) beam-column type; (e) – (f) dowel type

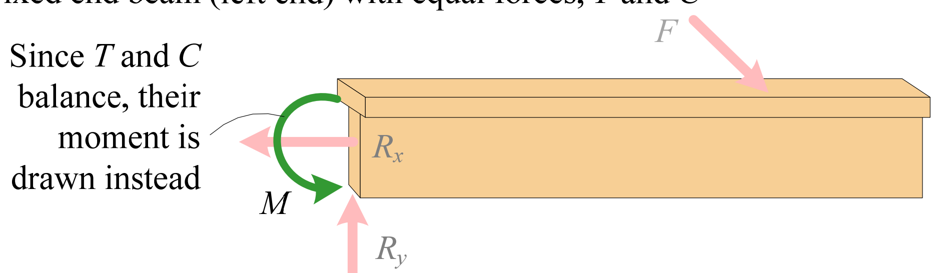
The shape of each mock-up support is designed to resemble the shape of the universal symbol. This is particularly evident in Figure 4, as the profile of the support closely resemble the shape of the universal symbol for a pin support. When each type of support is introduced, the universal symbol is presented simultaneously so that students can witness the behavior of the physical model and immediately associate it with the idealized representation (symbol) that they will routinely encounter when solving mechanics problems.

The presence or absence of three scalar reactions (two forces and one moment) is demonstrated by applying forces and a moment to each support. For example, the instructor applies a gentle horizontal force to the roller support (Figure 5) and it will immediately begin rolling. This demonstrates that the support does not offer any restraint to sliding (translation), thus, a horizontal force reaction is not generated. Similarly, a vertical downward force is applied to the support and, since it does not accelerate vertically, the presence of a vertical force reaction is confirmed. Lastly, a moment is applied to the bolted wooden bar to create free rotation. This freedom to rotate proves to students that a moment reaction is not generated by a roller support. A force diagram of the support is then drawn on a whiteboard to summarize the individual scalar reactions.

Based on the instructors' experience, students have substantial difficulty understanding the source or mechanism by which a moment reaction is generated in a fixed support (Figure 7). The moment reaction can be demonstrated by applying a force to the T-beam shown in Figure 7(b) and Figure 8(a) (shown as *F*). Students are then asked to predict how the beam would behave at the joint if the rigid metal bracket on the top were removed. They should realize that the top of the beam would shift outwards (+*x* direction). Similarly, the absence of the bracket on the bottom of the joint would allow the beam to shift inwards towards the column (–*x*). This should convince students that the brackets at the top and bottom of the joint would provide horizontal forces and, in their absence, would allow the beam to rotate. This effect is better communicated to students with a drawing similar to that shown in Figure 8(b). Building onto their prior knowledge of a couple moment, it should become evident to them that the presence of two forces (that are equal in magnitude, but opposite in direction) establishes the elusive moment reaction, *M*.



(a) Fixed end beam (left end) with equal forces, *T* and *C*



(b) Fixed end beam (left end) with equivalent couple moment reaction, *M*

Figure 8. Free Body Diagrams used to demonstrate the mechanism of a moment reaction

<u>Recommendations</u>: When demonstrating other support reactions such as the 3D ball-and-socket (B&S), it is critical that students are aware that B&S *bone* joints in the human body do not exert moments. This is often a source of confusion since students recognize that the human arm in Demonstration #1 was a cantilever and, thus, a moment reaction must exist at the shoulder joint. This is true, but the moment is created by the shoulder muscles; the bones themselves are free to rotate and offer no moment resistance. This fact should be explicitly conveyed to the students.

Demonstration #4: Cutting the Cheese Beam

<u>Overview</u>: This demonstration introduces the concept of generating an internal bending moment in a beam due to an applied shear force. The deformation of the beam also serves as a primer for mechanics of materials concepts, namely, horizontal shear, as well as flexural and shear strengths of beams.

Student Learning Outcomes: ability to: recognize that the application of an external shear force produces an internal bending moment in a beam

Resources: block of cheese (at least 6" span and 1 in^2 cross-section), 2 lengths of PVC pipe, knife

Preparation time: 1 minute

Demonstration time: 3 minutes

Procedure: As shown in Figure 9(a), a block of cheese is propped onto roller supports to create a beam with a span length of about 5". A vertical shear force is applied via a knife at midspan, Figure 9(b). As the knife presses downward, the top of the beam compresses while the bottom may begin to crack in tension. Students should realize that the top of the beam is resisting a compressive force, while the bottom resists a tensile force. Since the beam is not accelerating horizontally, the forces must balance and the net effect is an internal bending moment. A Free Body Diagram can be drawn of a section of the beam (either to the right or left of midspan). The internal bending moment can be identified in a manner similar to that presented in Figure 8(b). The demonstration can be repeated by turning the knife on its side to simulate shear from a distributed load.

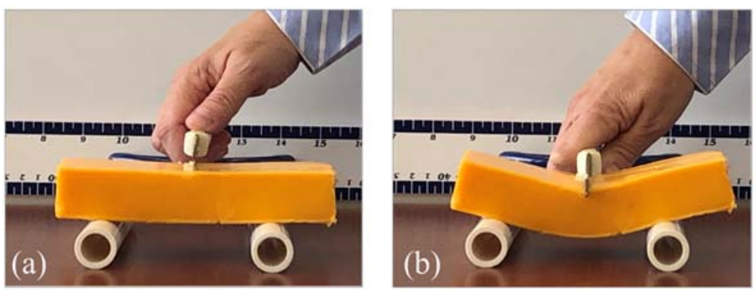


Figure 9. Cheese beam (a) prior to cutting and (b) near failure

Recommendations: Cheese selection should focus on semi-hard types that are easy to cut and exhibit substantial deflection that students can witness. Cheddar cheese was selected for those reasons, and the absence of a pungent odor. Soft cheeses could also be utilized, but should be frozen overnight and refrigerated just prior to use.

Demonstration #5: Breaking Bread

Overview: This food activity demonstrates the difference between positive and negative shear in a beam using individual slices of bread as differential elements subjected to shear.

Most students quickly grasp the concept of beam elongation under the action of tension forces, and deflection of a beam due to bending moment. This is likely because they can *visualize* these effects. However, since shear deformation is not readily visible in most beams, discerning between positive and negative shear is a relatively abstract concept for them. Providing a clear visualization of shearing in an entity common to all students (such as food) may enable students to gain a fundamental understanding of shear behavior. Thus, a loaf of bread is utilized such that each slice of bread serves as a differential element that can be displaced due to shearing action.

A rubber bearing pad could work equally as well, though the intent is to utilize materials that are familiar to students and that they can readily access outside the classroom.

Student Learning Outcomes: ability to distinguish between positive and negative shear

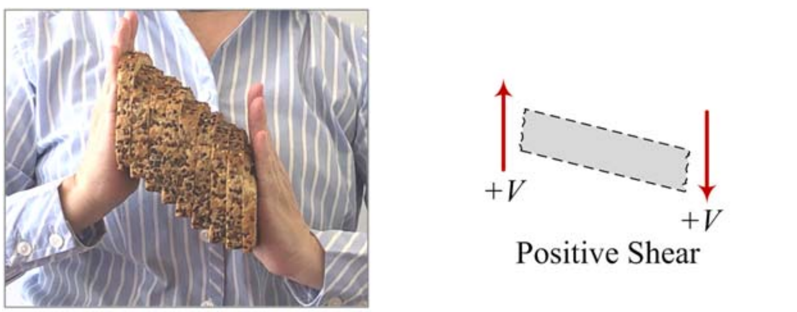
Resources: loaf of pre-sliced bread, peanut butter [optional], knife [optional]

Preparation time: 10 minutes

Demonstration time: 2 minutes

Procedure: This demonstration can be conducted using an entire loaf of bread (still in its cellophane wrapping), loose slices of bread, or slices of bread joined together using an adhesive such as peanut butter. If opting for peanut butter, several slices should be prepared in advance with thin layers of peanut butter on all sides (except for the end slices). Each slice should be bonded to its neighbor with a vertical offset of about ¼".

The instructor holds the bread beam with his/her hands vertical and parallel to the bread slices, as shown in Figure 10. Nominal shear forces are applied to the bread to maintain it in the deformed state shown (positive shear). The beam is then turned around such that negative shear is demonstrated to the students in a similar manner.



(a) Shearing of bread beam   (b) Positive shear representation

Figure 10. Bread beam and corresponding sign convention

Recommendations: In terms of bread selection, the multi-grain type is preferred since it is more rigid than white bread. Prior to conducting this demonstration, it may be prudent to notify students that peanut butter will be utilized. If a student has an allergy to peanuts, the instructor can find an alternative adhesive to bond the slices.

Demonstration #6: The MVP Mnemonic

Overview: A mnemonic device is a technique used to improve one's ability to remember and recall important information. The device presented here illustrates a method to learn the sign convention for bending moment (*M*), shear force (*V*), and axial force (*P*) in beams.

Student Learning Outcomes: ability to recall and draw the positive conventions for bending moment, shear force, and axial force

Resources: none

Preparation time: none

Demonstration time: 2 minutes

Procedure: The mnemonic device is shown in Figure 11, and is a form of an expression mnemonic since it utilizes both whole words and the first letter of particular words in a sentence. It is interpreted as follows:

- Axial force: Positive axial force corresponds to an elongation or stretching due to tension. The letter "A" in the word "And" represents axial, while the word "Stretch" implies tension.
- Bending moment: Similar to smiling, the deformation of a beam that results in a concave up orientation represents positive internal bending moment. The letter "B" in the word "Because" denotes bending, while the smiling behavior is analogous to concave up.
- Shear force: Shear forces that produce a clockwise (CW) deformation represent positive shear behavior. The first letter of each of the words "Can't Wait" are used to remember clockwise (CW), while the "S" in "Statics" denotes shear.

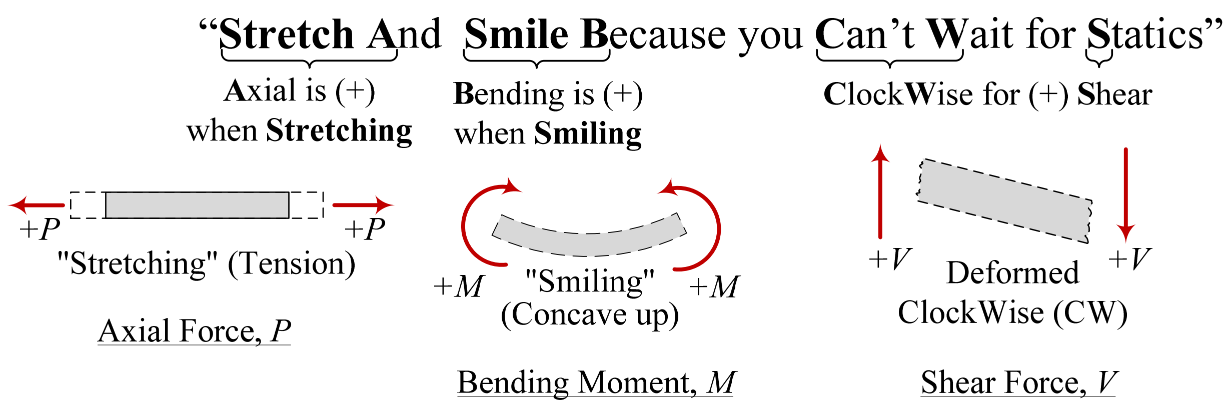


Figure 11. Mnemonic used to illustrate the positive sign convention for internal effects in beams

Recommendations: The mnemonic should be presented to students immediately following the bread and cheese demonstrations mentioned earlier.

4. Assessment Results and Discussion

Summative assessment was conducted using a 35-question IRB-approved questionnaire (survey) disseminated online to students at the conclusion of each semester after final grades are released. Question #13 prompted students to consider the following statement:

"*The statics demonstrations carried out during the lectures helped me to understand the concepts.*"

Respondents then rated their agreement with the statement on a scale from "strongly disagree" to "strongly agree". 47 undergraduate students (who completed the statics course at the authors' institution within the past 3 years) responded to the question above to evaluate their respective instructor. The results are presented in Figure 12.

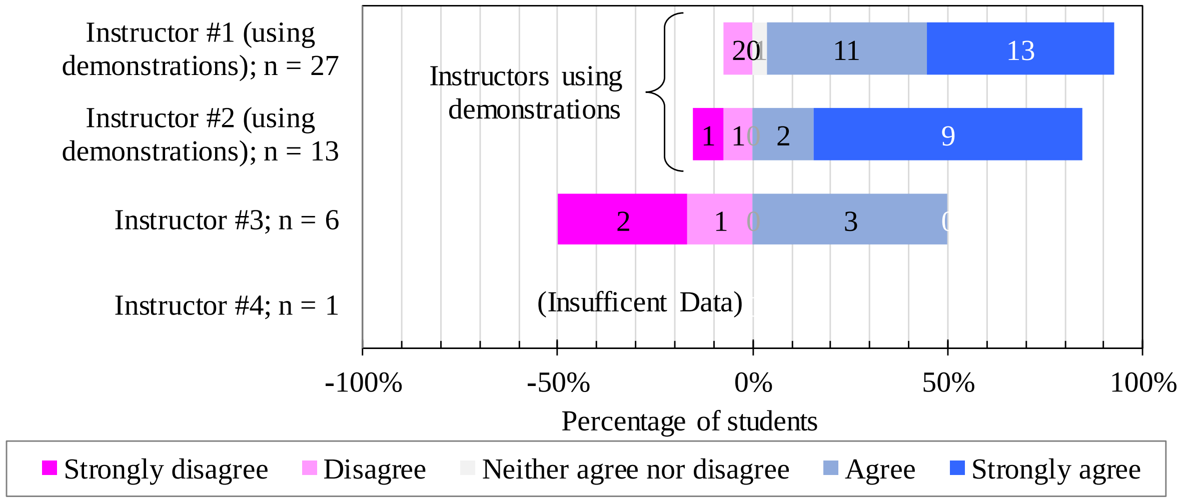


Figure 12. Results of student perceptions of the demonstrations' effectiveness

For the two instructors (#1 and #2) that regularly implement the statics demonstrations, the results indicate that an overwhelming majority of the students (89% and 85%, respectively) believe that the demonstrations positively contributed to their understanding of statics. Instructor #3 did not employ the demonstrations in this paper. Only 50% of the respondents agreed that his/her demonstrations were effective in helping learn the concepts. Similarly, Instructor #4 did not employ demonstrations. However, there was only one student respondent.

A statistical analysis was performed to compare the mean effectiveness scores for the instructors. Each student response was assigned a numerical value that ranged from 1 for "Strongly disagree" to 5 for "Strongly agree". The null hypothesis was that the mean effectiveness scores for Instructors #1 and #2 (experimental groups using demonstrations) were equal to the mean score of Instructor #3 (control group not using demonstrations). An alpha level of 0.05 was utilized for all statistical testing.

The respondents for Instructor #1 reported higher effectiveness scores ($M = 4.30$, $SD = 2.07$) than did those taking the course with Instructor #3 ($M = 2.67$, $SD = 1.63$), $t(6) = 2.56$, $p = 0.04$. Similarly, the effectiveness scores for students enrolled with Instructor #2 ($M = 4.31$, $SD = 2.08$) were significantly higher than the control group with Instructor #3, $t(9) = 2.30$, $p = 0.05$. In both cases, the differences between the experimental group and the control group were statistically significant to conclude that the mean scores were different. It is important to note that this study was not planned with the objective of using students (taught by Instructor #3) as a control group. Accordingly, Instructor #3 was not discouraged from utilizing his/her own demonstrations or teaching approaches.

Since the survey falls under the purview of research, students were not mandated to complete it. Thus, the overall response rate (27%) was lower than desired. The authors are in the process of identifying strategies to increase the participation rate, as well as utilization of graded assignments to conduct a more thorough assessment. Unfortunately, it is difficult to obtain a control group (without demonstrations) for comparison. For the foreseeable future, the authors of this paper are expected to be the sole instructors of the statics courses at their institution. To deliberately remove the demonstrations in one course section (to serve as a control group) would be inappropriate given their apparent positive effect on learning.

5. Conclusions and Recommendations

This paper presented six demonstrations that can be carried out in introductory mechanics courses, especially Statics and even Mechanics of Materials. The fundamental concepts of moments, moment arms, and couple moments are presented in two consecutive demonstrations that may directly involve student participants. The third demonstration utilized physical manipulatives that demonstrate the various types of support reactions that engineering students will encounter on a daily basis. The remaining three demonstrations focused on the behavior of beams and frame members. A beam of cheese is utilized to visualize bending moment, while a loaf of sliced bread is deformed to visualize shear. The mnemonic device offers a unique approach to memorizing the positive sign convention when assigning the directions of internal effects (M, V, and P) in structural members.

A statistical analysis was performed on the results from student surveys, which asked students to rate the effectiveness of the classroom demonstrations using a 5-point Likert scale. The mean effectiveness scores (4.30 and 4.31) from two experimental groups with different instructors were compared to that (2.67) from a third instructor that constituted the control group. The differences in mean scores (between each experimental group and the control group) were statistically significant using a significance level of 0.05. Thus, the authors conclude that the demonstrations contribute to improved student learning based on students' own perceptions. A direct comparison using a common assignment administered in the experimental and control groups would be ideal to rate the effectiveness of the class demonstrations. The authors are currently reviewing legacy data in an attempt to identify previously graded assignments that could serve as a control group that did not utilize the demonstrations.

Based upon the authors' experience teaching Statics and Mechanics of Materials courses, several recommendations are offered:

- Classroom demonstrations and interactive exercises should first build onto the everyday experiences of the students, including childhood and adolescent experiences. Once the students are able to relate to the concept, it can be gradually linked to engineering applications. For example, introducing the concept of moment by discussing an automobile's transmission will likely alienate many students in the course who are not familiar with powertrains. However, all students will have a trove of life experiences from their childhood. It is that collection of experiences that such demonstrations should stem from.

- Physical manipulatives (like those in Demonstration #3) were designed specifically for the lecture related to support types. Unfortunately, the students cannot retain the manipulative upon the conclusion of the lecture. It is ideal if the manipulatives are everyday items that are accessible to students outside of the classroom. In that fashion, students can obtain their own manipulative and collaborate with others, revisit the manipulative to reinforce their understanding outside of the classroom, apply to homework problems, and demonstrate it to their peers.

- Instructors should be cognizant of the educational background and composition of their student audience. A broad diversity in concentration areas may also warrant a more diverse set of demonstrations and example problems to be solved. If the course is composed of students from widely varying engineering curricula, the demonstrations could be tailored to highlight relevance to each discipline.

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