

## Improving retention of student understanding by use of hands-on experiments in Statics

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Carisa Ramming joined the faculty at Oklahoma State University as an assistant professor in January 2009 after a stint as a visiting professor in the School of Architecture during the 2007-2008 academic year. Professor Ramming is a graduate of Oklahoma State University with a Bachelor of Architectural Engineering degree in 2001 and dual masters degrees; Master of Science in Civil Engineering with an emphasis in Construction Engineering and Master of Architectural Engineering in 2004. Before returning to academia, Professor Ramming worked as a consulting engineer for Wallace Engineering in Tulsa, OK, primarily designing large structural steel retail facilities and obtained her license as a professional engineer in the state of Oklahoma. Professor Ramming is a member of the American Society of Engineering Educators and the Oklahoma Structural Engineers Association. She has served the engineering community previously as Director, Vice-President, and President of OSEA. Currently, Professor Ramming is the National Delegate for the state of Oklahoma to the National Council of Structural Engineering Associations and Oklahoma Eastern Chapter Young Member Group. Professor Ramming is the advisor for OSU's student chapter of the Architectural Engineering Institute. Professor Ramming recently co-authored Civil Engineering & Architecture: Workbook for Project Lead the Way which provides curriculum for science, technology, engineering, and mathematics education used in middle and high schools. She was also named the Outstanding Faculty Member from the College of Engineering, Architecture and Technology by the The Panhellenic Council and Interfraternity Council in 2010 and 2012 and awarded the Halliburton Young Teaching Award in the College of Engineering, Architecture and Technology in 2013.

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# Improving Retention of Student Understanding by Use of Hands-on Experiments in Statics

## Abstract

*When a course in the Engineering Science of Statics is taught to a large number of students, how can the the multiple topics covered in the class be presented in a manner to increase the student's understanding of the material? Statics is one of the foundation courses for an engineering student's education, and the topics learned in this course must be retained for use in follow-on courses in engineering. For a class with several hundred students in a semester, the problem becomes even more difficult as overhead projections are often the only way of presenting to a class of this size during theory sessions. Theory sessions of the course are not able to present material to small groups, a manner in which students might be more likely to retain what they have been presented. However, during the course discussion labs, where the number of students does not exceed 24 per instructor, students should be able to have more of a personal relationship with the instructor, and thus potentially better understand and retain material presented to them. Within the College of Engineering, Architecture and Technology at Oklahoma State University, continued low test scores along with an unfavorable percentage of students retaking this course have led to a focus being placed on searching for ways of formatting the course in a manner to allow students to better retain the material presented. As a result, the professors involved in this course have been tasked with improving student's ability to retain knowledge obtained, measured through test scores, as well as decreasing the percentage of students required to re-take the course due to non-passing grades. It is also generally agreed upon that if students better understand the beginning engineering courses, the retention of students within the college can be improved, which is always a topic of concern in higher education.*

*One method that is being explored to improve student's understanding in this course is the use of hands-on activities in the discussion labs that reinforce topics presented in the theory sessions. By utilizing these activities, students should be able to draw on the experiences to retain knowledge of individual topics. This paper will explore methods currently being utilized in a large format course in Statics, and in particular, how the use of hands-on experiments during discussion labs can lead to an increase in student's understanding. Evaluation of the methods used will be based on homework and exam questions pertaining to specific topics in the course lab exercises.*

## Introduction

According to a recent report from the President's Council of Advisors on Science and Technology, the nation's workforce will face a shortfall of one million college STEM graduates over the coming decade<sup>1</sup>. The need for graduates in science, technology, engineering, and mathematics (STEM) is growing while the supply is shrinking. Thus, it is imperative that higher education do their part to properly recruit and retain the students within their programs.

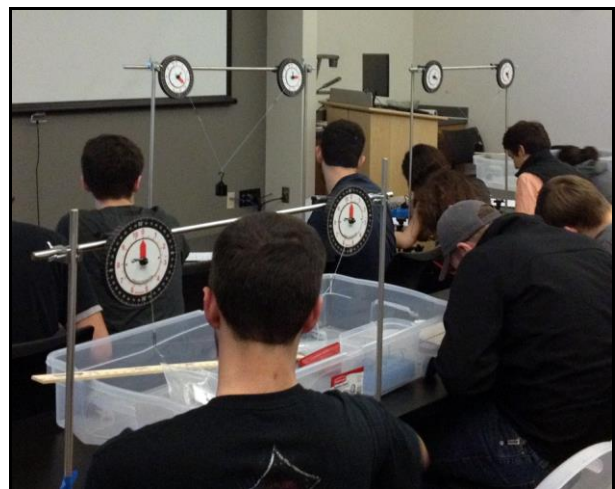
At Oklahoma State University, retention of students has become a focus within the College of Engineering, Architecture and Technology. The majority of students leaving our program do so in the first two years of the curriculum, and we have tasked ourselves with investigating why this occurs. The first two years of an engineering student's curriculum is heavily loaded in mathematics, physics, and beginning engineering courses, such as Statics. A student's success in these courses can be a crucial factor in their decision to stay or leave STEM education. It is the belief of many that if students can be *properly engaged* in the learning process early on in their education career, with theories and concepts being successfully taught to students, they will find the course relevant and enlightening, and will be more likely to continue along their chosen path of education. One problem that arises is determining what is meant by '*properly engaged*', and how this can be accomplished in the short amount of time we have with students in our courses.

Introductory STEM courses provide the building blocks for student success in later courses, and in the Fundamentals of Engineering (F.E.) exam. This exam must be passed successfully by all engineering students seeking professional licensure, and is an exam where the theories and concepts introduced in the STEM courses are tested. The problems involved with teaching students in STEM courses exist across the country in large and small programs alike, and there is an ongoing effort being made to address these concerns. Major universities such as MIT and West Point have successfully adopted an approach that offers hands-on experience in the beginning STEM courses, and the use of similar experiences are now being explored in the Statics course taught at Oklahoma State University.

The engineering science course in Statics is the first true engineering course that most of the students in our program enroll, and the endeavor of completing this course successfully can be a shock to many. This course has been referred to historically as a 'weed out' course within the college, and one of the perceived reasons for this has always been the disconnect between the students and the professor teaching the course. Additionally, for a course such as this that is required to be taught in a large classroom setting, the question arises of how to present the multiple topics in the class in a manner that gives students the best understanding of the material? Engineering Statics is one of the foundation courses for an engineering student's education, and the topics learned in this course must be retained for use in follow-on engineering courses. For a class with enrollment ranging from 200 to 350 students per semester, the problem becomes even more difficult as overhead projections are often the only way of presenting to a class of this size during theory sessions. However, during the course discussion labs, where the number of students does not exceed 24 students per instructor, students should be able to have more of a personal relationship with the instructor, and thus potentially better understand and retain material presented to them. Within the College of Engineering, Architecture and Technology, continued low test scores along with an unfavorable percentage of students retaking this course have led to a focus being placed on searching for ways of teaching the course in a manner to allow students to better retain the material presented. As a result, the professors involved in this course have been tasked with improving student's ability to retain knowledge obtained, which is measured through homework assignments and test scores, as well as decreasing the percentage of students required to re-take the course due to non-passing grades. It is also generally agreed upon that if the students better understand the beginning engineering courses, the retention of students within the college can be improved, which is always a topic of concern in higher education.

This course is taught each semester and is offered to the entire university, with the enrollment averaging 340, 220, and 35 students in the fall, spring, and summer semesters, respectively. This three credit hour course meets three days a week for fifty minute theory sessions, and on a fourth day for a discussion session. New topics are introduced in the course at a fast pace, and not more than one week of the sixteen week course is devoted to any one topic. With the number of students enrolled in the course, large lecture halls are used for theory sessions in which theory, concepts, and methods are introduced. A number of examples are also worked during these sessions to further introduce the topics. This portion of the course is taught by the professor, utilizing power point presentations for the theory presented, and hand-worked examples on overhead projections during class time. In addition to the theory sessions, the weekly discussion session consists of students separated into sections of 24 students, with the session being taught by a teaching assistant. During the discussion sessions, example problems are worked, reviews for exams are given, homework is returned and discussed, and questions on specific topics can be brought up by the students. It is during these discussion sessions that students can interact with the instructors in a smaller setting. However, these sessions are not without their issues, such as the perception that they are not worthwhile since they are taught by teaching assistants instead of the professor for the course. While the logistics of teaching multiple discussion sessions by the professor alone is not realistic, there are ways in which these discussion sessions can be improved upon to enhance the student's educational experience. It was the goal of the faculty of this course to enable the discussion sessions to become more interactive and thus engaging to the students, resulting in an enhanced educational opportunity.

Over the past five years, the professors involved in this course have begun to reformat this course in a manner that will hopefully increase a student's understanding of the material presented and thus increase retention in the course and within our college. Several revisions are being introduced, including online resources for students to utilize within the course, an increase in available tutoring sessions, and the introduction of hands-on experiments for use in furthering the understanding of individual topics within the course. It was concluded that the use of this type of active learning setting within the course might be a method to achieve improved retention of theory by our students.<sup>2</sup>



*Figure 1 and 2: Students working through the Equilibrium hands-on exercise during discussion lab in Statics*

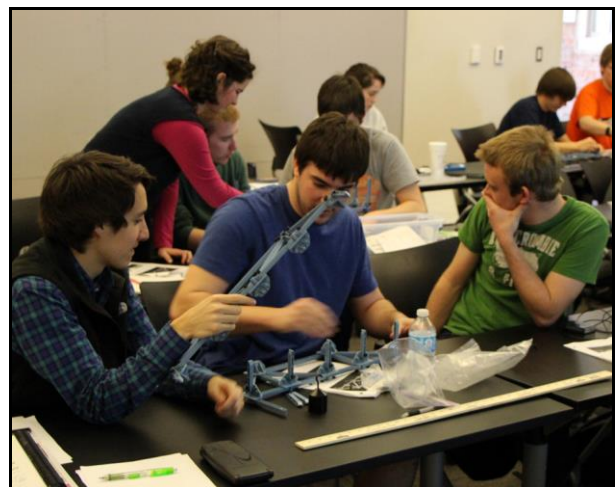
A survey was conducted via [www.surveymonkey.com](http://www.surveymonkey.com) in the Spring of 2013 of the students that were currently re-taking the course. When asked what played the biggest factor in the outcome of their grade, 50% indicated that exams gave them the most difficulty and 62.5% said that truss analysis was the most troublesome topic. The poll also questioned attendance of lecture and discussion. In lecture, 62.5% attended regularly while 37.5% attended somewhat or never. When asked about discussion, the numbers shifted with 50% attending regularly and 50% somewhat or never. With the intent of changing the structure of the discussion section in mind, the question “would hands-on laboratory experiments be of interest to you?” was asked and was met with a response of 83.3% for yes.

Based on this data, the instructors were hopeful that the addition of the hands-on experiments would have a compounding effect. If the students were interested in the discussion activities, they would see the value in attending. This boost in attendance and the re-formatted activities would see a rise in exam and homework scores which were listed as the two top factors in reasons for undesirable grade outcome.

The use of hands-on lab exercises in discussion labs that reinforce topics presented in the theory sessions has moved from being an experimental tool to one that is now utilized across the course. These labs are shown in their entirety in the Appendix.

By utilizing these lab exercises, students should be able to draw on their experiences to retain knowledge gained on individual topics. Three times during the semester, students are given the opportunity to utilize the weekly discussion lab time to work through hands-on lab exercises that explore the theory taught in course on individual subjects. The lab exercises consist of a series of educational tools, which have been provided through support from our college as an initial offering to help increase student retention within this course and the engineering program.

The lab exercises are performed in teams of three, and are structured such that they can be completed in a single discussion session, without the need for additional work outside of class. Students are given a worksheet that outlines what they are trying to accomplish with the exercise. There are currently three lab exercises being utilized, covering the topics of particle equilibrium,



*Figure 3 and 4: Students working through the Truss hands-on exercise during discussion lab in Statics*





**Figure 5 and 6:** Students working through the Friction hands-on exercise during discussion lab in Statics

truss structures, and static friction. Prior to each of the lab exercises, the theory basis is disseminated to the students during the theory sessions of the course, and examples have been worked, with the premise that the use of hands-on lab exercises directly relating to this theory should reinforce knowledge of the subject.

Students are given a handout for each hands-on exercise, consisting of several questions that must be answered. For each of these, a *purpose statement* gives a brief description of what is expected to be learned. Additionally, there is a *pre-lab question*, which is an observational question that students should be able to answer with a little thought. Next, students work through the exercise, drawing Free-Body Diagrams and performing calculations to arrive at the answers required. A second question is then asked that requires analyzing the problem from a different perspective. Finally, a *conclusion* question is asked that requires the student to evaluate their answers and make a determination whether they are correct, and if incorrect, what the reasons for the error might be.

The process upon which these lab exercises are based allows students to better understand how a problem they may see as homework or on an exam originates, and why the information provided on different problem types is important in arriving at the correct answer. Additionally, hands-on lab exercises allow students to ask questions based on the physical models they are interacting with, to understand free body diagrams more fully, and allow students to see errors in calculations. One interesting outcome of these lab exercises involved the fact that theoretically, certain assumptions are made to arrive at correct answers, and these assumptions are not fully realized in the lab exercises. One example of this involves the truss exercise. Theory states that for a statically determinate truss, the connections are assumed to be pinned, and load is only applied at the joints of the truss. Because both of these assumptions cannot be exactly modeled, the values obtained in the lab exercises do not match theoretical results. Often there are conversations that spring from these differences in results that allow students to better understand theoretical versus real world application of engineering problems.

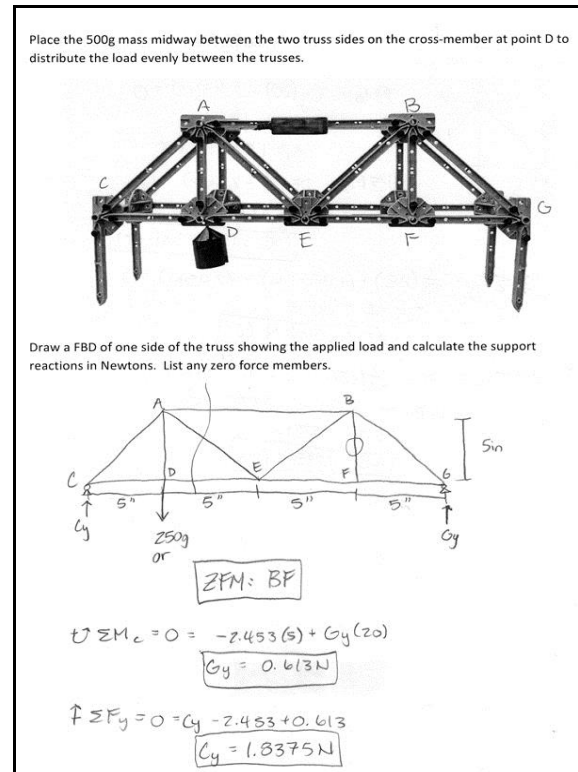
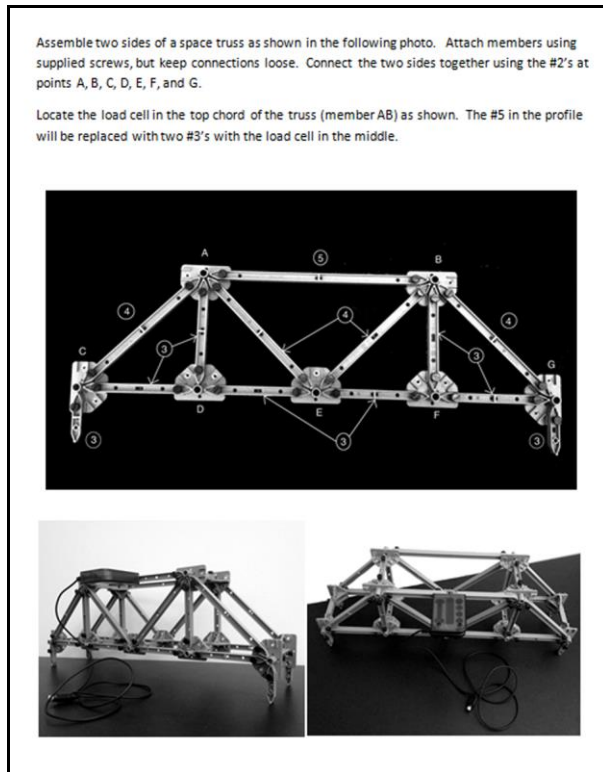


Figure 7 and 8: Examples of handout and student work on the Truss hands-on exercise

Based on the perceived positive reception of the inclusion of these, a study of the effectiveness of utilizing hands-on experiments during discussion labs was warranted. This study was used to determine if this learning method leads to an increase in students understanding of individual topics. Evaluation of individual homework and exam questions pertaining to specific topics in the course were used to assess the success of these educational experiences. This data was compared with previous semesters of the course in which the hands-on lab exercises did not occur, and this comparison was used to evaluate if this course change helped students to better understand and retain the course curriculum being taught.

## Assessment

Assessing the use of these lab exercises within the course was based on three criteria, and for each of the criteria, data was compared for semesters that included the lab exercises versus semesters that did not. Also, the summer semesters with class sizes from 30 to 40 students have a typical classroom experience with no discussion session. In addition, the majority of these students is often ahead of schedule in the curriculum and thus could be thought of as advanced. For these reasons, the summer semesters were omitted from the assessment.

First, individual homework problem grades were compared and are shown in Table 1.

Homework Average			
Problem	No Labs	With Labs	% Change
Equilibrium	80.5%	88.4%	9.8%
Truss	51.0%	77.5%	52.0%
Friction	60.5%	84.7%	40.0%

*Table 1: Homework averages for hands-on laboratory topics*

Second, individual exam problem grades were compared and are shown in Table 2.

Exam Problem Average			
Problem	No Labs	With Labs	Change
Equilibrium	71.2%	72.4%	1.7%
Truss	71.1%	73.6%	3.5%
Friction	74.5%	78.7%	5.6%

*Table 2: Exam problem averages for hands-on laboratory topics*

Third, overall exam grades were compared and are shown in Table 3.

Overall Exam Average			
Exam	No Labs	With Labs	Change
Exam #1	76.8%	72.5%	-5.6%
Exam #2	68.2%	69.4%	1.8%
Exam #3	76.9%	75.6%	-1.7%
Exam #4	71.6%	81.0%	13.1%
Average	73.4%	74.6%	1.6%

*Table 3: Exam averages for hands-on laboratory topics*



There exist several conditions that could be said to skew results of this study. One of the most obvious is that the same problems for homework and exams cannot be given each semester, thus the comparison is on the theory of the problem, and not the exact problem itself.

### **Future enhancements**

The success of this program is largely due to two factors. First, the enthusiastic reception from the students in this course was paramount to its success. Students overwhelmingly approved of the lab exercises, both from the standpoint of better understanding the theory on which the lab exercises were based, and from the standpoint that being actively involved in the course gives them ownership. Many students expressed their pleasure with the lab exercises being part of the course, and often questioned if more of these activities could be included in the course. Second, without the support from the administration within our college, this program could not have been instituted, and the continued support is something we feel is necessary to advance the learning lab kits for our students. Funding for the purchase of a large number of the exercise equipment has led to positive results within the course. With the administration's continued support, we hope to increase the number of lab kits available for use, as well as increase the topics covered with the hands-on labs. We would like to increase the number of hands-on labs from three to five, with the two additional labs covering the topics of force system resultants (such as reactions), and machine systems (such as pulleys).

### **Conclusion**

Research has shown that for those students who have difficulty learning in traditional classroom settings, active learning formats could be helpful in achieving a positive outcome. The use of hands-on labs within the introductory engineering science course of Statics has been shown to increase students understanding of the multiple topics within this course. In the first two semesters of implementation by the entire class in Statics, the use of lab exercises has resulted in slight increases in averages on homework and exam grades. It is anticipated that as this course format change is refined, the goal of increased retention of students in this course and within the College of Engineering, Architecture and Technology at Oklahoma State University will be achieved.

### **References**

<sup>1</sup> Knutson, Kari. "Study Looks at Why Students Leave STEM Majors." University of Wisconsin-Madison News, Web. 16 October 2012.

<sup>2</sup> Felder, Richard M., and Linda K. Silverman. "Learning and teaching styles in engineering education." *Engineering education* 78.7 (1988): 674-681.

<sup>3</sup> Baldwin, Roger G. "The climate for undergraduate teaching and learning in STEM fields." *New Directions for Teaching and Learning* 2009.117 (2009): 9-17.

<sup>4</sup> Fairweather, James. "Linking evidence and promising practices in science, technology, engineering, and mathematics (STEM) undergraduate education." Board of Science Education, National Research Council, The National Academies, Washington, DC (2008).

<sup>5</sup> Coller, B. D. "An experiment in hands-on learning in engineering mechanics: statics." *International Journal of Engineering Education* 24.3 (2008): 545.

## Appendix

### Equilibrium of a System ENSC 2113 Fall 2013

#### Purpose

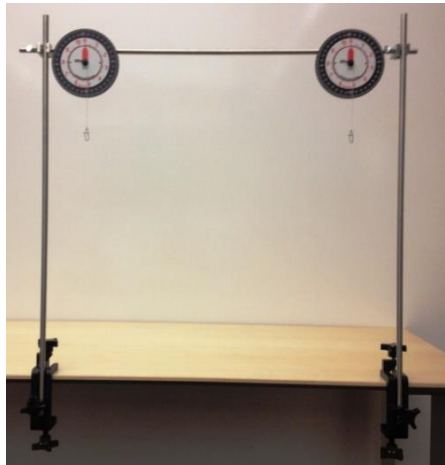
Verify the vector sum of the forces acting on an object in equilibrium is zero.

#### Pre-lab question

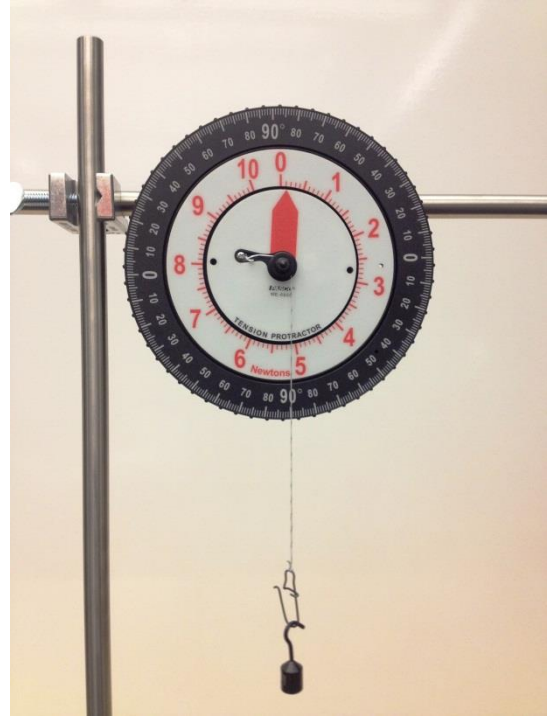
If an object is suspended by two strings at two different angles, which string will have the greater tension?

#### Set-Up

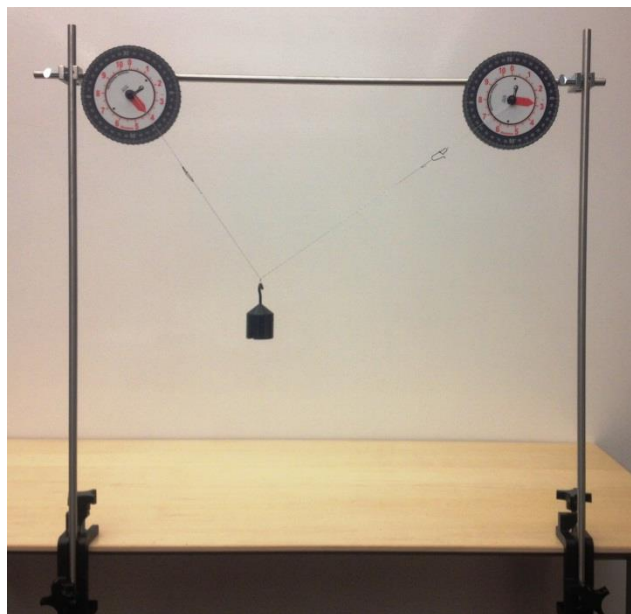
Clamp two rods to the table approximately 32 in (81.3 cm) apart using the large clamps. Attach two protractors to a cross rod and clamp this rod between the vertical rods using the small clamps.



Without anything attached to the string, adjust the thumb screw in the back until the force scale reads zero. After the force scale is zeroed, hang a small mass (10 g) from the tension string of the protractor. Adjust the outer ring to where the string aligns with 90 degrees.



Attach the ends of the provided string to the clips on the protractor strings. Hang the 500 g mass from the loop located along the length of the string.



### Procedure

Record the magnitude of force and the angle for each string and record them in the table below.

Tension	Magnitude of force (N)	Angle (degrees)	Hanging Mass (kg)
String 1			
String 2			

Calculate the weight of the hanging mass in Newtons.

Draw the Free Body Diagram of the system.



Calculate the x and y components of the tension of each string and record them in the table below.

Weight of Hanging Mass	
x-component of Tension 1	
x-component of Tension 2	
y-component of Tension 1	
y-component of Tension 2	

Calculate the sum of the forces in the x and y directions. Do they equal zero? Why or why not?

If the string is rated to hold 133.5 N (30lb), then what is the largest mass than can be suspended from the system?

## **Truss Analysis – Method of Sections**

### **ENSC 2113 Fall 2013**

#### **Purpose**

Calculate internal force in a truss using the method of sections in truss analysis.

#### **Pre-lab question**

What assumptions are made about trusses in rigid body mechanics?

#### **Set-Up**

##### **Parts Needed:**

(7) - #2's

(18) - #3's

(8) - #4's

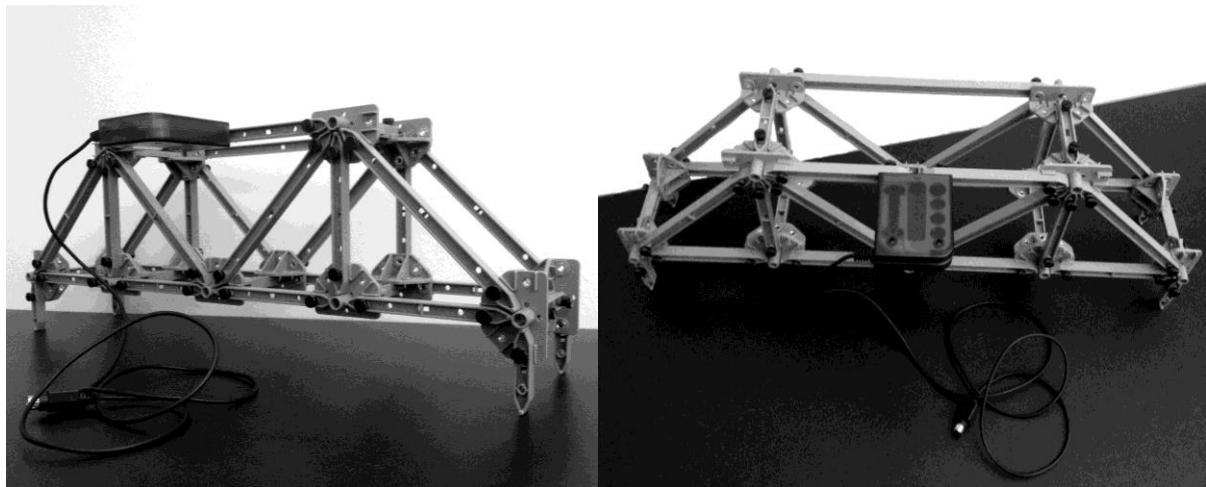
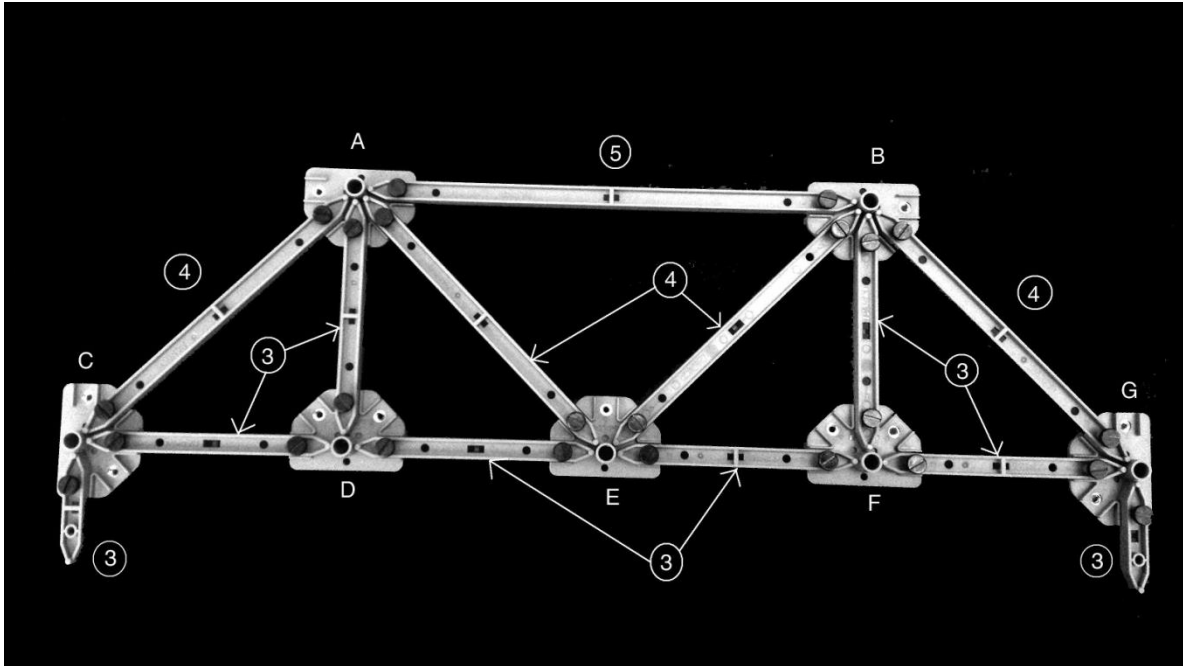
(1) - #5

(14) – gusset plates

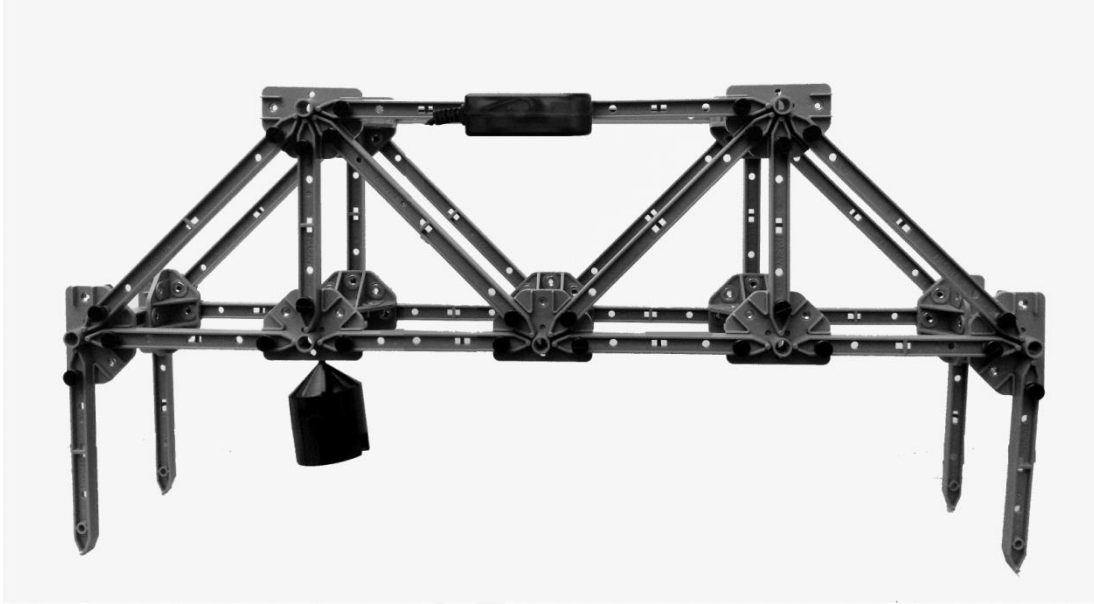
(1) – 5N load cell

Assemble two sides of a space truss as shown in the following photo. Attach members using supplied screws, but keep connections loose. Connect the two sides together using the #2's at points A, B, C, D, E, F, and G.

Locate the load cell in the top chord of the truss (member AB) as shown. The #5 in the profile will be replaced with two #3's with the load cell in the middle.



Place the 500g mass midway between the two truss sides on the cross-member at point D to distribute the load evenly between the trusses.

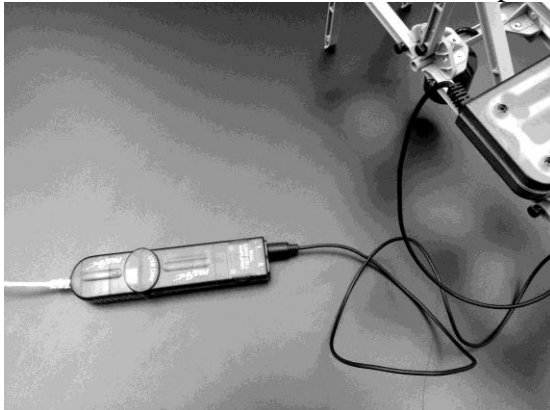


Draw a FBD of one side of the truss showing the applied load and calculate the support reactions in Newtons. List any zero force members.

Using method of sections, calculate the force (N) in members AB, AE, and DE and state if they are in tension or compression.



Attach the load cell to the load cell amplifier as shown.



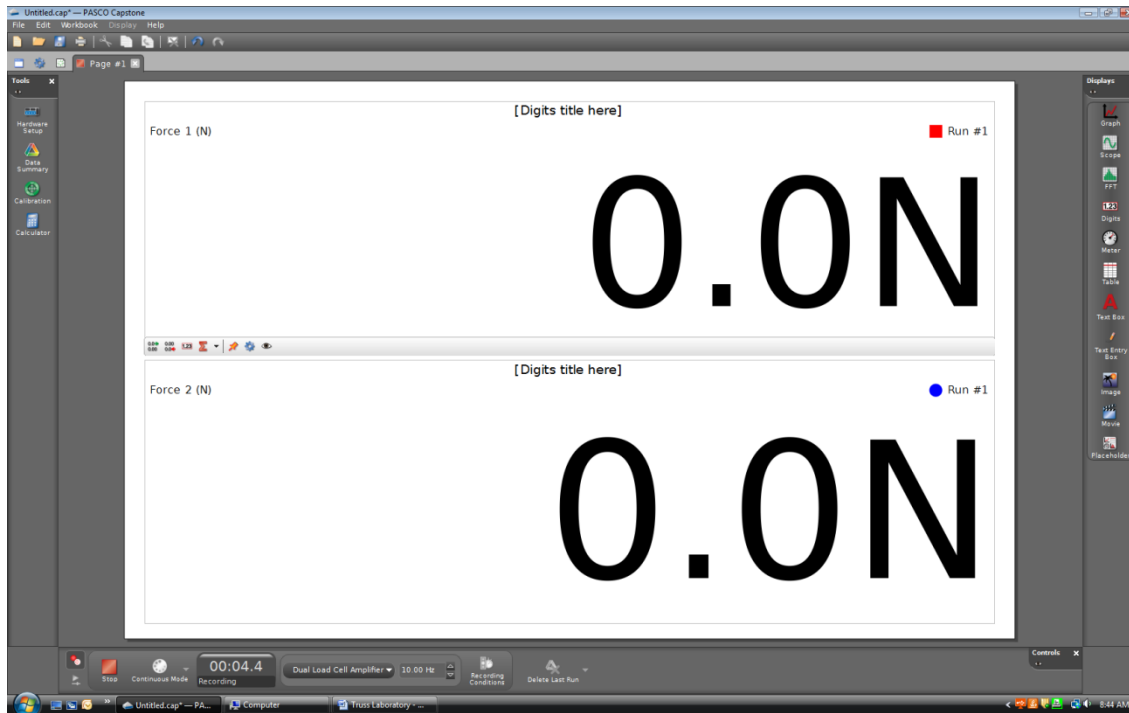
Remove the mass and calibrate the load cell by pressing the tare button on the side of the amplifier.



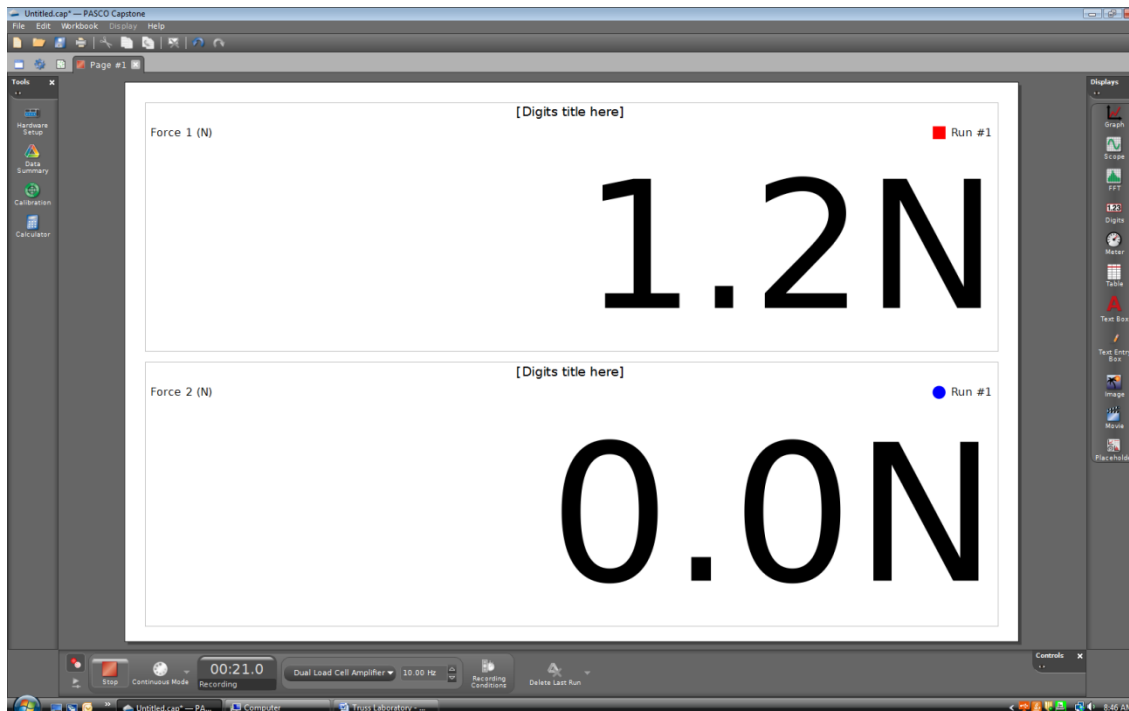
Open PASCO Capstone to the screen shown below. Force 1 will read the force in member AB where the load cell is connected. Note that tension will read as negative and compression as positive.



Press record in the bottom left hand corner. The measurement should read zero.



Re-apply the mass midway between the trusses at point D.



The force in member AB will read as Force 1.

Record the force shown for Force 1 (member AB) below.

How does this compare to your truss analysis calculations?

Why does the experiment ask that the connections remain loose?

## Sliding Friction

### ENSC 2113 Fall 2013

#### Purpose

Comparing the coefficient of sliding friction to different surface areas and contact surfaces.

#### Set-Up

Parts Needed:  
Statics Board  
Pulley  
Mass and Hanger Set  
Inclined Plane  
Friction Block  
Scale  
Thread

#### Procedure – Part 1

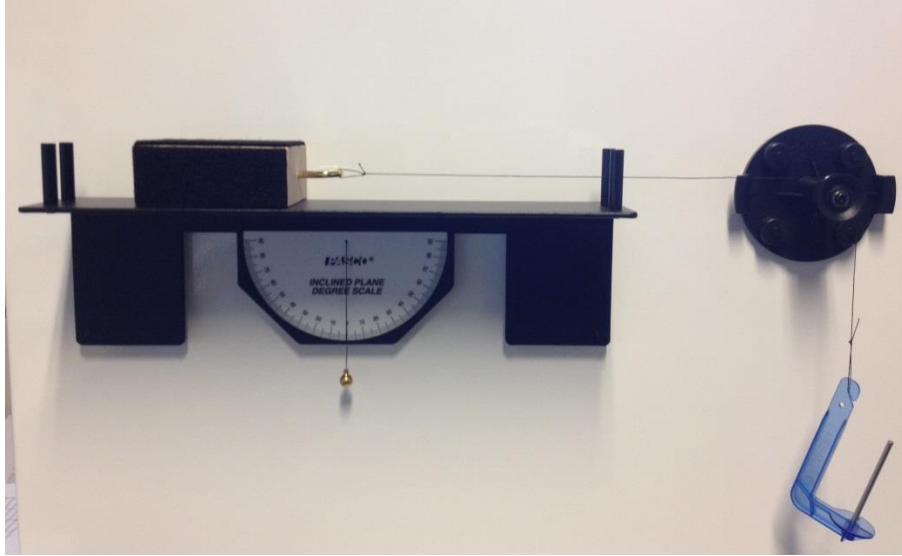
Measure the weight of the friction block and the mass hanger and record the values below.

Friction block = \_\_\_\_\_ g

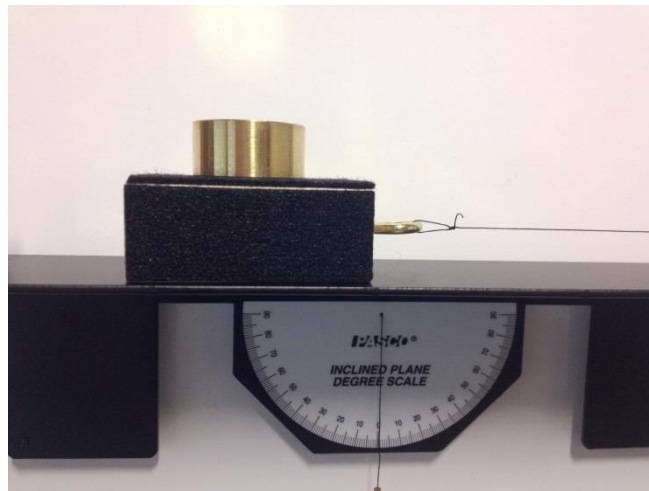
Mass hanger = \_\_\_\_\_ g

Mount the inclined plane on the magnetic board and use the plumb bob to level the plane. Set the friction block on the inclined plane and use thread to connect it over a pulley to a mass hanger as shown. The thread should be parallel to the inclined plane.





The frictional coefficients of two surfaces and two surface areas will be measured. Place the frictional block large, wooden side down on the inclined plane. Add mass to the top of the friction block to increase the normal force as shown in trials 1-6 below. Record the total mass and the hanging mass (mass hanger and added masses) in the table below.





Add or subtract masses on the mass hanger until the friction block begins to move at a constant velocity with a slight push. If the block stops, the mass is too light, if it accelerates, the mass is too heavy.

Trial	Added mass (kg)	Total Mass of Block, <b>M</b>	Normal Force, <b>FN=Mg</b>	Hanging mass, <b>m</b>	Friction force, <b>f=mg</b>	Coefficient of friction, $\mu = f/FN$
1	0.00					
2	0.05					
3	0.10					
4	0.15					
5	0.20					
6	0.25					

For trials 7-10, keep the total mass of the friction block constant and document how each of the four surfaces reacts to the added hanging mass.

Trial	Surface	Total Mass of Block, <b>M</b>	Normal Force, <b>FN=Mg</b>	Hanging mass, <b>m</b>	Friction force, <b>f=mg</b>	Coefficient of friction, $\mu = f/F_N$
7	Wood, Large					
8	Felt, Large					
9	Wood, Small					
10	Felt, Small					

### Questions

In trials 1 through 6, what happens to the sliding friction as the normal force increases?

In trials 1 through 6, what happens to the coefficient of friction as the normal force increases?

How does the sliding friction for the large wood surface compare to the sliding friction for the large felt surface?

How does the sliding friction for the small wood surface compare to the sliding friction for the small felt surface?

Based on your measurements, does the sliding friction between two objects depend on the materials that are in contact?

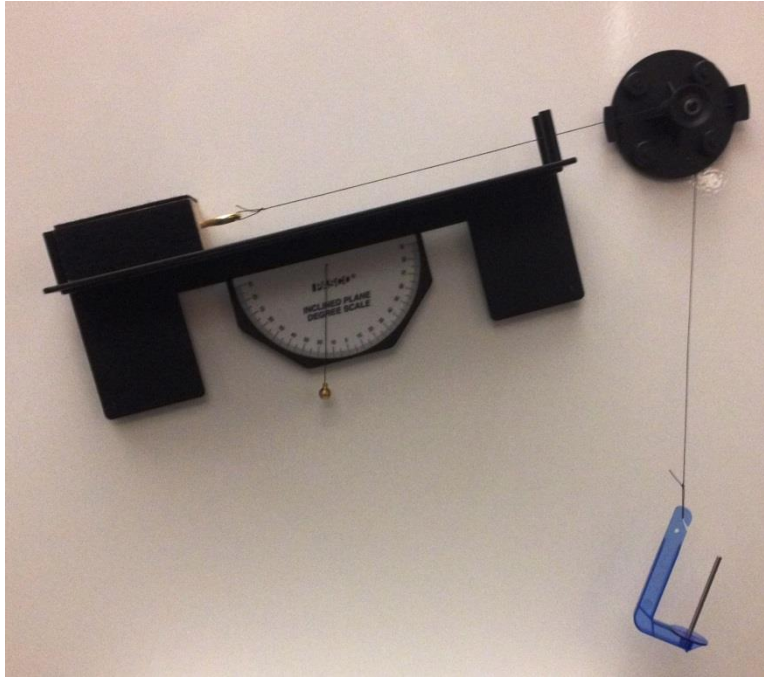
How does the sliding friction between for the large wood surface compare to the sliding friction for the small wood surface?

How does the sliding friction for the large felt surface compare to the sliding friction for the small felt surface?

Based on your measurements, does the sliding friction between two objects depend on the surface area between the objects?

## Procedure – Part 2

Set the angle to 15 degrees and adjust the pulley so that the thread is parallel to the friction block as shown below.



Draw the Free-Body-Diagram of the friction block:

Adjust the mass on the mass hanger until the weight of the hanging mass is enough so that the friction block moves at a very slow, constant speed up the incline after a small push.

Record results in the table below.

Angle, $\theta$	Block Mass, $M$	Hanging mass, $m$	Parallel Component, $F_{\text{parallel}} = Mg \sin \theta$	Normal force, $F_{\text{perpendicular}} = FN = Mg \cos \theta$	Friction force, $f = \mu FN$	Tension, $T = mg$
15 degrees						

Sum of the parallel components of the block's weight and the sliding frictional force,  
 $F_{\text{parallel}} + f_k =$  \_\_\_\_\_

Question

How does the tension in the thread compare to the sum of the parallel components of the block's weight and the sliding friction force?