AC 2011-2312: IMPLEMENTATION OF MINI-LECTURES IN DREAM: RIGOR IN AN INFORMAL, DESIGN BASED HIGH SCHOOL MENTORING PROJECT

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Implementation of Engineering Mini-Lectures in DREAM: Rigor in an Informal, Design Based High School Mentoring Project

ABSTRACT

The impact of mini-lectures on mentees' understanding of pre-engineering concepts is investigated in the K-12 engineering outreach program DREAM. Past results have shown that coupling informal, recitation-like sessions with DREAM hands-on learning projects improves mentees' (high school students) understanding of pre-engineering concepts as compared to mentees that do not participate in such discussions. In fact, without these informal sessions, higher-order concepts can become further muddled, even when significant improvements are observed in first-order concepts. This study aimed to determine if structured mini-lectures could achieve similar gains in mentee understanding, with a more formal and repeatable approach. No decrease in mentee performance was observed, as had sometimes previously occurred on high-level questions. However, gains were modest. This is attributed in part to the fact that many concepts tested here were lower-level when compared to previous work. As would be expected, mentees demonstrate higher correct response rates on these questions initially, and therefore most gains are small. Discussions with teachers at the DREAM schools suggest that high expectations are critical to improving the rigor in DREAM. The mentees are more motivated and focus more intently on mini-lectures that introduce completely new material, as compared to those that simply reinforce their coursework.

THEORETICAL FRAMEWORK

DREAM - Achievement through Mentorship is designed to introduce underrepresented, underprivileged high school students (mentees) to engineering and help them prepare for the challenges of an undergraduate engineering degree program. DREAM has three main goals that have evolved and come into focus over the four years of the program's existence. First, DREAM seeks to change mentees' perceptions of what is possible, leading them to a better quality of life through college education and subsequent rewarding and lucrative engineering and STEM careers. Second, DREAM prepares mentees for the rigors of undergraduate STEM education by forming connections between engineering applications and high school classes, and promoting enrollment in upper-level math and science courses. Third, DREAM prepares mentees for the challenges of university admissions through ACT and SAT prep and assistance with college applications and essays.

DREAM has steadily evolved since its inception in 2007, as the unique needs of the underserved mentees have been better understood. Developing mentoring relationships through the completion of a design project was the initial focus and remains the heart of the program. This allows volunteer mentors (primarily undergraduate engineering students) to successfully introduce engineering to their mentees. Early survey results have demonstrated this impact[1].

As the first cohort of mentees progressed through their second year of the program, it became evident that, while many developed a measurable passion for engineering, few were able to understand the importance of the pre-engineering concepts and mathematics in their design work. This shortcoming was addressed starting in fall 2010 (year four of the program) by introducing mini-lectures to clarify the relationship between the design projects and high school math, science and physics classes. Enrollment in these "quality" courses is now promoted throughout the program. The mentors instill in the mentees the confidence needed to take and succeed in these classes, which provide the necessary background to study engineering at the college level. Furthermore, the mini-lectures have proven effective for teaching and reinforcing pre-engineering concepts. This is true even for higher-level concepts than would typically be presented at the high school level.

Inventories administered before and after DREAM generally show significant improvements in mentee pre-engineering understanding, with correct responses to the primary concept increasing from typically less than 50% to 85-97% in past implementations[2]. Short-term retention studies and comparisons with same-school control groups confirm that the effect is statistically significant. Data from fall 2010 is presented here. The emphasis here is the implementation of mini-lectures, and how these assist to increase expectations.

Currently, DREAM is in place in three urban Houston, Texas high schools: Stephen F. Austin High School (AHS), Cesar E. Chavez High School (CHS) and KIPP Houston High (KIPP). As stated previously, DREAM works to serve underrepresented minority students, which can be seen from each of the school profiles for the 2008-2009 academic year. The demographics of the student body at AHS are broken down as follows: 95% Hispanic/Latino, 4% African-American, 1% Caucasian, less than 1% Asian-American, and less than 1% Native American. Of the 1920 total students 100% qualify for Title I status, with 91% receiving reduced price or free lunches[3]. A similar demographic and economic profile exists at CHS, where of the 2606 students, 83% are Hispanic/Latino, 12% are African-American, 3% are Asian-American, 2% are Caucasian, and less than 1% are Native American. 100% of the students qualify for Title I status and 85% receive reduced priced or free lunches[4]. KIPP varies slightly from the other two schools since it is a charter school and requires students be accepted into college in order to graduate. A total of 448 students are enrolled in KIPP, of which approximately 76.9% are Hispanic/Latino, 11.5% are African-American, 7.7% are Asian-American, and 3.9% are Caucasian. About 90% of the students qualify for Title I status and receive reduced price or free lunches[5].

LITERATURE REVIEW

Studies have shown that integrating traditional learning with hands-on learning environments have beneficial outcomes. Project Lead the Way implemented a hands-on learning program to supplement high school pre-engineering courses, concluding that their students outperformed students of comparable backgrounds in reading, mathematics, and science tests[6].

Other programs have adopted similar approaches of creating kinesthetic learning programs within the context of preexisting curricula. The Secondary Schools and Queensland University of Technology Engineering Activity Kits (SQUEAK) program was implemented in Australia to attract students of secondary schools to engineering careers. Like Project Lead the Way, the SQUEAK program designed hands-on projects to match to students' coursework[7]. The Virginia Middle Schools Engineering Education Initiative (VMSEEI) created engineering testing kits (ETKs) to facilitate engineering instruction within science and mathematics courses and has built on anecdotal evidence from teacher feedback to improve students' understanding of fundamental engineering concepts[8,9,10]. The Integrated Teaching and Learning (ITL) Program at the University of Colorado at Boulder developed a Creative Engineering course for students at a nearby high school. This course focused on hands-on design based engineering in conjunction with the high school curriculum and demonstrated that students had increased confidence in the use of engineering methods to solve problems[11].

Research on learning styles reflects the positive impact of integrating kinesthetic learning environments with traditional learning structures. A recent study showed that learning is a conglomeration of a variety of interactions[12]. The results demonstrated that the integration of active learning styles with traditional learning offers increased opportunity for retention and understanding. This suggests that the implementation of mini-lectures in the DREAM program will enhance the mentees' understanding of engineering concepts that are present in the design projects.

RESEARCH QUESTION

Theoretically and empirically, a strong relationship between academic expectations and student achievement has been well-established[13]. Schools with exceptional levels of achievement consistently demonstrate an environment of high expectations[14]. When expectations are clearly defined and students are held accountable, students strive to meet expectations[15]. Heightened teacher expectations for students, coupled with teachers' perceptions of greater administrative support, have been linked to successful teaching and learning outcomes[16]. Academic success is therefore dependent on setting high expectations that challenge students to think critically and providing tools that allow students to comprehend the concepts at hand.

As mini-lectures have expanded to all three high schools, DREAM has significantly raised the expectation level for the mentees. This is accomplished by teaching and holding the mentees accountable for freshmen and sophomore college-level engineering concepts such as stress and strain. Anecdotally, mentees enjoy the higher-order concepts even though they may not fully understand them. Mentors and teachers have observed a heightened level of effort and interest, proportional to the increasing rigor of the material presented[17]. The higher-order concepts catch the attention of the mentees, thus they actively listen and try harder to understand the concepts.

In an analysis of teacher and student narratives, researchers found the most effective teaching of mathematics was characterized by supplementing high academic expectations with after-school tutorials, weekend study sessions, university partnered tutoring programs, and procedures to regularly assess student progress[18]. DREAM mentees have similar opportunities to reinforce their understanding of higher-level concepts coupled with regular assessments via the Intuition Inventories (I.I.) and Pre-engineering Concepts Inventories (P.C.I.). For example, in the cantilever project in spring 2011, mentees applied the concepts they learned in the mini-lectures immediately to their project designs.

Mentees' intuition and ability to predict the outcome of physical situations (*i.e.* statics in the 2010-2011 implementation) are measured via Intuition Inventories (I.I.). Previous research on DREAM suggested that mentee understanding of pre-engineering concepts is improved by coupling hands-on learning with informal teaching of these concepts. Mentors deliver these teachings in a uniform manner consistently across campuses by following lesson plans such as those included in Appendix C. Although the informal teachings are inherently difficult to reproduce in a systematic way, DREAM has created a uniform teaching curriculum and has implemented long-term consistent measurements via the I.I. to qualitatively assess comprehension. This poses the question:

Can mini-lectures on pre-engineering concepts provide similar learning outcomes when coupled with hands-on activities in DREAM?

METHODOLOGICAL CONSIDERATIONS

DREAM seeks to motivate high school students to attend a university in science, technology, mathematics, and engineering (STEM) fields. This goal of inspiring students towards STEM fields is achieved through the mechanism of a design competition. Rice University undergraduate mentors meet with high school mentees to work on a design, and conversations about college form naturally.

DREAM is implemented at the three participating schools in three different formats due to the varying structures of each high school. At AHS and KIPP, DREAM is an after school activity. At AHS, participation is voluntary and mentees self-select to participate. At KIPP, the mentees select DREAM as one option among several programs available during the mandatory after-school Co-Curricular (CCO) sessions. At CHS the mentees are enrolled in the Academy of Engineering curriculum and DREAM is offered to certain classes, with mandatory attendance.

The mentoring format varies somewhat across the campuses with considerations for both the setting (in-class or after school) and the number of mentees participating. At AHS, one mentor typically works with two to three mentees, while KIPP and CHS have larger groups due to increased structure provided at those schools. KIPP groups are four mentees per mentor, while CHS has groups of five or six mentees per mentor.

DREAM has been expanded to include seven to eight weeks of mentoring and working on the design project. In conjunction with designing and building the prototypes, pre-engineering concept mini-lectures, relevant to the project, are presented. Over the span of a year a topic (e.g. statics, gravitational acceleration, buoyancy) is covered through two distinct design projects. In the fall semester a design project is selected to match the year's topic, and a mini-lecture series is used to introduce concepts underlying the design. In the spring semester a second design project that also matches the year's topic, but is more difficult, is selected. Along with this second topic a more in-depth, mathematically based mini-lecture series is provided. A mini-lecture, which lasts about seven to ten minutes, is delivered each week by one of the mentors at each school. Mini-lecture content is standardized to minimize the bias in various mentors' presentations. Lectures are delivered using visual aids. Interaction with the mentees is facilitated through questions posed at key points during the mini-lecture.

The 2010-2011 academic year pre-engineering topic was static equilibrium. In the fall semester, the design project involved building a spaghetti bridge to withstand a point load. The project description, rules and timeline are given in Appendix A. The corresponding mini-lecture series introduced fundamental concepts and vocabulary such as force and stress from a high-level perspective. In the spring semester the mentees were tasked with designing a cantilever beam, from which a load was suspended. The associated mini-lecture series provided a more mathematical understanding for the concepts introduced in the spring semester. The content of the mini-lecture series for the fall 2010 and spring 2011 semesters is provided in Appendix C.

Inventories are used to test mentees' understanding of concepts throughout the program. Intuition Inventories (I.I.) are used in the fall and focus on measurement of intuition about the outcomes of situations that are presented. Pre-engineering Concept Inventories (P.C.I.) are used in the spring. These include both intuitive questions, and questions that focus on algebraic representation, mathematical evaluation and free response. Each semester, prior to the start of DREAM, inventories are administered to the mentees to gauge their baseline comprehension of fundamental engineering concepts. Inventories are also administered at the end of the program on DREAM Day. Here the DREAM Day and initial pre-DREAM I.I.s from fall 2010 are compared to measure increases in mentee intuition for engineering concepts. The exact I.I. used is included in Appendix B.

PROJECT DESCRIPTION

The design project implemented during each semester of DREAM facilitates the mentoring experience and provides an engaging mechanism for mentees to experiences some of the pre-engineering concepts that are discussed in the mini-lectures. Although the design project is only used as a vehicle for the primary goals of DREAM, the projects also introduce the mentees to concepts such as designing under constraints and optimization.

For the fall 2010 project, mentees were tasked with designing a bridge out of spaghetti and glue that would span a one-foot gap. The bridges were then subjected to incrementally increasing point loads until failure. A maximum weight constraint for the bridge was also enforced. The final score for the bridge was based on efficiency defined by the following equation:

$$Final\ Score = \frac{Weight\ Held\ at\ Failure}{Weight\ of\ Bridge}$$

This type of scoring introduced basic optimization concepts to the mentees. It reinforced the need to create an efficient bridge rather than simply a bulky, dense bridge that can support a great mass. The full project description for the fall 2010 project as provided to the mentees is included in Appendix B.

The spring 2011 project built upon the concepts of the fall 2010 project with more emphasis on quantitative evaluation, both in the mini-lectures and in the design project. In spring 2011 mentees are tasked with designing a cantilever out of popsicle sticks and glue. Weight, minimum length, and maximum length constraints were imposed on the device. The final score for this project was based on a weighted efficiency score shown below:

$$Final\ Score = \frac{Weight\ Held\ at\ Failure}{Weight\ of\ Bridge}\left(\frac{Length\ of\ Cantilever\ in\ Inches}{12}\right)^2$$

By weighing the efficiency score by the length of the cantilever squared, a new level of mathematical complexity was introduced to the mentees. This facilitated more quantitative discussions between mentors and mentees and opened new avenues of optimization for the design of the cantilevers.

RESULTS AND DISCUSSION

Observations from spring 2009 I.I. uncovered an interesting trend. When asked about the invariance of gravitational acceleration (Q1), more than half of mentees initially incorrectly thought that a more dense object would fall faster than a less dense object of the same volume and shape. However, 56-67% of mentees were initially able to predict that an object thrown down would fall faster than if the same object were dropped (Q2). Hence, mentee intuition about the impact of initial velocity was at a fair level. Correct responses to Q1 increased dramatically by the end of DREAM (DREAM Day) at all three schools, indicating the ability of DREAM to teach potentially counterintuitive pre-engineering concepts. However, correct responses to Q2 increased only at AHS, and actually decreased at CHS and KIPP. These results are reproduced in Figure 1 from Houchens *et al.*[19], which also includes control data that demonstrates that these results are purely influenced by DREAM, and not the classes the mentees were attending.

In spring 2009, mentors at all three schools actively focused on the concept of invariance of gravitational acceleration, the concept tested in Q1, while working with their mentees. However at AHS impromptu, informal discussions often took place, allowing for sufficient time to also reinforce and separate the concept of initial velocity. At CHS and KIPP, this higher-order concept was not addressed, and mentees actually lost intuition, as they incorrectly came to perceive that the initial velocity was somehow trumped by invariance of gravitational acceleration in Q2 - they could not separate the concepts based on the instruction they received.

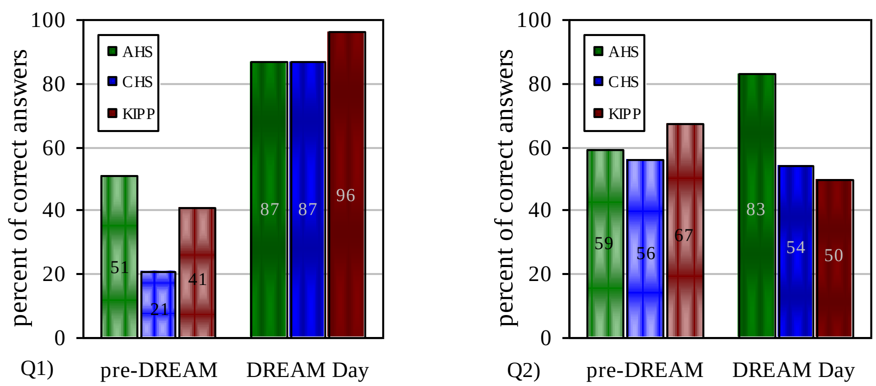


Figure 1: Correct pre and DREAM Day responses to the three I.I. questions, spring 2009

Based on this research, mini-lectures were implemented in fall 2010 with the hope that these could replace the informal discussions that proved so effective at AHS, while providing a reproducible means for imparting the desired pre-engineering knowledge.

The fall 2010 design competition focused on bridge building. The design rules are given in Appendix A and the Intuition Inventory in Appendix B. The concepts in the I.I. focused primarily on statics, bending and failure. Questions 1 and 4 were meant to test the same concept (beam supports and bending moments), as were questions 2 and 5 (area moment of inertia).

Control data taken at KIPP demonstrated that Q1 and Q4 showed internal consistency. A chi-square test of answers to a post-DREAM (December 2010) administration of the I.I. to 108 (36 each from 9^{th}, 10^{th} and 11^{th} grade) randomly selected non-DREAM KIPP students showed significance at the 0.024 level. Q2 and Q5 did not demonstrate the internal consistency desired, based on this same control sample. Question 3 was found to be invalid and results are not included here. Question 6 showed overly inflated improvements due to inherent teaching to the test in the mini-lecture on torsion, thus those results are also not included here.

Only mentees who completed both the initial and final (DREAM Day) I.I.'s were included in the analysis. Comparing the DREAM Day data from KIPP mentees to the control taken post-DREAM showed that mentees outscored non-mentees on all four questions of interest (Q1,Q2,Q4,Q5). Interestingly, non-mentees post-scores were significantly higher than mentees pre-scores on Q1 (74.1% versus 54.8%) and Q4 (70.4% versus 50.0%), suggesting that DREAM may be attracting mid or lower performing students at KIPP. Differences between non-mentees post-scores and mentees pre-scores were not significant on Q2 and Q5.

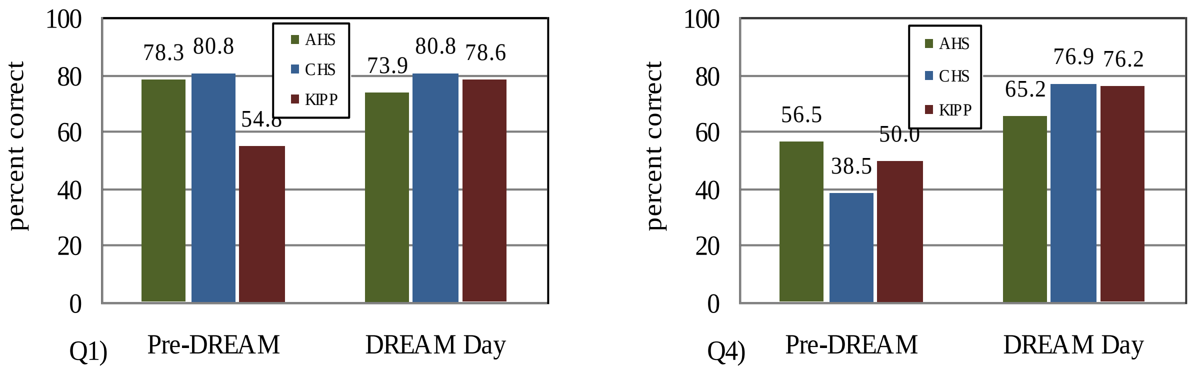
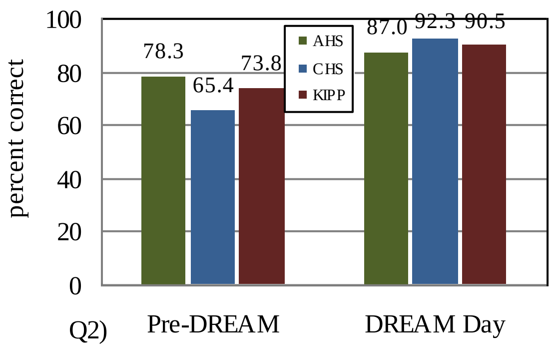


Figure 2: Correct pre and DREAM Day responses to the I.I. Q1 and Q4, fall 2010
$N_{AHS} = 23$, $N_{CHS} = 26$, $N_{KIPP} = 42$

As can be seen in Figure 2, correct response rates were high when mentees were asked to evaluate the deflection of a beam with supports closer or farther apart (Q1). The only decrease was observed at AHS, corresponding to one mentee. More significant improvements were observed in Q4, particularly at CHS and KIPP.

Modest to fair gains were observed in Q2, as shown in Figure 3. Again the high initial results leave less room for improvement. Similar trends were observed on Q5 at CHS and KIPP, with no improvement from the initial high scores of approximately 76% correct. Interestingly, significant improvement was observed at AHS, though the initial poor performance is difficult to explain.



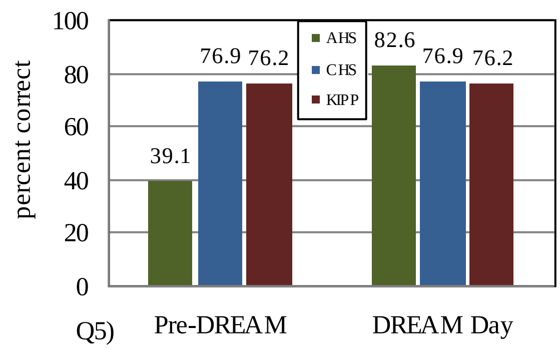


Figure 3: Correct pre and DREAM Day responses to the I.I. Q2 and Q5, fall 2010
$N_{\text{AHS}} = 23$, $N_{\text{CHS}} = 26$, $N_{\text{KIPP}} = 42$

CONCLUSIONS

Overall, the data does not fully answer the question regarding the effectiveness of mini-lectures for teaching pre-engineering concepts when coupled with hands-on design activities. That mentees performed uniformly well on DREAM Day inventories provides support for this educational methodology. Unlike in the previous semesters at CHS and KIPP, no significant reduction in understanding was observed. This suggests that mini-lectures are likely effective. However, because of the high pre-DREAM performance on some questions, it is impossible to state definitely that this is true.

It is thought that mini-lectures will have a bigger impact when more difficult concepts are in question. For example, the invariance of gravitational acceleration, independent of object density, is counterintuitive for most high school students who have not yet seen this material. This accounts for the large gains observed in Q1 in spring 2009, shown in Figure 1. In contrast, mentees generally displayed much higher initial correct intuition for the bending concepts tested in fall 2010. The cantilever concepts of spring 2011 will provide more definitive outcomes, as these proved more challenging in pre-DREAM inventories.

The overall improvement observed here and in past research is consistent with the notion that design projects allow for introduction and reinforcement of engineering concepts and help mentees build intuition. Some balance between informal hands-on learning and formal instruction will clearly result in the largest improvement in mentee understanding, but that balance may be significantly skewed by the specific concept, and how intuitive or counterintuitive it is. Anecdotally, teachers and mentors have observed that high expectations have increased the motivation of the mentees. When faced with university level concepts, presented without reliance on pre-requisites, mentees will persevere to understand the material and apply what they have learned to their design projects.

REFERENCES

1. Campo, L., Rice, S., Rimer, D. & Houchens, B. Mentoring to impassion the study of engineering in underrepresented high school students via a design mechanism. *Proceedings of the 2009 ASEE Annual Conference and Exposition* AC 2009-659, (2009).
2. Goza, A., Garland, D. & Houchens, B. Physics and mathematics learning outcomes of underserved and underrepresented DREAM mentees at three urban high schools. *Proceedings of the 2010 ASEE Annual Conference and Exposition* AC 2010-296, (2010).
3. HISD Stephen F. Austin High School Profile. *http://dept.houstonisd.org/profiles/Austin_HS.pdf* (2008).
4. HISD Cesar E. Chavez High School profile. *http://dept.houstonisd.org/profiles/Chavez_HS.pdf* (2008).
5. Texas Education Agency 2007-2008 Academic Excellence Indicator System – KIPP INC CHARTER. (2008).
6. Bottoms, G. & Anthony, K. Project Lead the Way: A Pre-engineering Curriculum That Works. *South Region Educational Board* (2005).
7. Dawes, L. & Rasmussen, G. Activity and engagement – Keys in connecting engineering with secondary school students. *Proceedings 17th Annual Conference of the Australasian Association for Engineering Education* (2006).
8. Richards, L.G., Flaherty, J. & Cunningham, J. Assessing Engineering Teaching Kits for Middle School Students. *Proceedings of the 2004 American Society for Engineering Education Annual Conference and Exposition*
9. Richards, L.G., Laufer, G. & Humphrey, A. Teaching Engineering in the Middle Schools: Virginia Middle Schools Engineering Education Initiative. *ASEE/ISEE Frontiers in Education Conference* (2002).
10. Richards, L.G. & Schnittka, C.G. Workshop - Bringing Engineering into Middle Schools: Learning Science and Math Through Guided Inquiry and Engineering Design. *37 th ASEE/IEEE Frontiers in Education Conference* (2007).
11. Zarske, M.S., Kotys-Shwartz, D., Sullivan, J.F. & Yowell, J.L. Creative Engineering: Helping Ninth-Grade Students Discover Engineering. *Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition* (2005).
12. Dawes, L., Murray, M. & Rasmussen, G. Student experiential learning. *Proceedings of the 2005 ASEE/AaeE 4 th Global Colloquium on Engineering Education* (2005).
13. Johnson, J.P., Livingston, M., Schwartz, R.A. & Slate, J.R. What makes a good elementary school? A critical examination. *Journal of Educational Research* **6**, 339-345 (2000).
14. Schmoker, M. The results fieldbook. *Association for Supervision and Curriculum Development* (2001).
15. Stronge, J.H. Qualities of effective teachers. *Association for Supervision and Curriculum Development* (2002).
16. Jussim, L. & Eccles, S. Teacher expectations: Construction and reflection of student achievement. *Journal of Personality and Social Psychology* **6**, 947-961 (1992).
17. McKay, M. Best practices in K-12 and university partnerships panel winners, ASEE K-12 and Pre-College Engineering Division. *ASEE Paper number 2011-167, Proceedings of the 2011 ASEE Annual Conference and Exposition* (2011).
18. Kitchen, R. Closing the gap through an explicit focus on learning and teaching. *NCSM Journal of Mathematics Education Leadership* (2005).
19. Houchens, B.C., Bautista-Chavez, A.M., Castilleja, J.A.J., Jackson, R.W. & Goza, A.J. Learning outcomes and perceptions of underrepresented high school mentees targeted through engineering outreach. *P-12 Engineering and Design Education Research Summit, Seaside, OR* (2010).

Appendix A

DREAM Program - Competition Fall 2010
Spaghetti Bridge!

Objective:
Build a bridge using only dry spaghetti and glue that can span a 12 inch gap and support the most weight when weighed in the middle.

Timeline:

Week 1	Monday, Sept 13 & Tuesday, Sept 14 *Inventories and Surveys*	Introduction to the Program
Week 2	Monday, Sept 20 & Tuesday, Sept 21 *Mini-Lecture: An Introduction to Statics*	Design and Planning
Week 3	Monday, Sept 27 & Tuesday, Sept 28 *Mini-Lecture: Forces and Loads Part 1: Compression and Tension*	Design and Building
Week 4	Monday, Oct 4 & Tuesday, Oct 5 *Mini-Lecture: Forces and Loads Part 2: Point Loads vs. Distributed Loads*	Building
Week 5	Monday, Oct 11 & Tuesday, Oct 12 *Mini-Lecture: Statics and Stress*	Building + Testing
Week 6	Monday, Oct 18 & Tuesday, Oct 19 *Mini-Lecture: Tension and Compression in Bridges*	Building + Testing
Week 7	Monday, Oct 25 & Tuesday, Oct 26 *Mini-Lecture: Torsion and Shear Stress*	Building + Testing
Week 8	Monday, Nov 1 & Tuesday, Nov 2	Final Building + Testing, Packing

Tuesday, Nov 5th ***DREAM Day demonstration at Rice University***

Eligibility:
In order to qualify to win prizes at the DREAM Day competition, ***you must be present for at least 6 of the 8 after school sessions and attend DREAM Day*** itself. To track attendance, we will have a sign in sheet each day – please make sure to sign in so that we know you came!

Design Phase:
You will have eight weeks to design your launching device and build/test it before the final competition. You will be provided with a box containing dry spaghetti, glue, and wax paper to aid with the construction. ***Please write your team name on the side of the box*** so that you know which box is yours. If you need more supplies for the design phase, there are a few boxes with extra supplies. This is so that you can build and test more than one device before the real competition. Help yourself to what you need. Please inform one of the mentors if supplies are running low. You will need to have a complete and working design by DREAM Day.

Appendix A

Demonstration Day:

The DREAM Day Demonstration will consist of a display and testing phase.

Display:

During this phase you will display your device and it will be weighed and judged for the Most Creative Design prize. You will not be allowed to many any modifications to your device during this phase.

Testing:

After all weighing and judging has been completed, each team's device will be tested. For testing, the bridge will be spanned across a 12 inch gap and a metal bar with a basket below will be used to add weight to your structure. Weight will be added until the failure of your device and the final weight supported will be recorded.

Scoring

Your overall score will be determined as follows:

Overall Score = (weight in grams supported by device at failure)/(weight of device in grams)

The most creative prize will be awarded at the discretion of the panel of judges.

Materials List:

You will be provided spaghetti, glue, and wax paper in order to construct your device. However, the wax paper cannot be used as part of your final device and is provided to aid in construction only.

Rules and Limitations:

1. Your device may not be larger than 20" by 20" by 20" and may not weight more than 2.5 kilograms.
2. Your final device may only consist of spaghetti and glue.

Prizes:

Prizes will be awarded to the teams as follows:

Grand Champion (highest overall score)
Second Place (second highest overall score)
Third Place (third highest overall score)
Most Artistic/Innovative Design (get creative!)

To make sure that you're eligible to win prizes on the final competition day, make sure that you show up to ***at least five after school sessions and sign in every time***.

Questions:

If you have any questions, please ask your mentor or send an e-mail to ***Insert Head Mentor Names and Emails***. Enjoy!

Appendix B

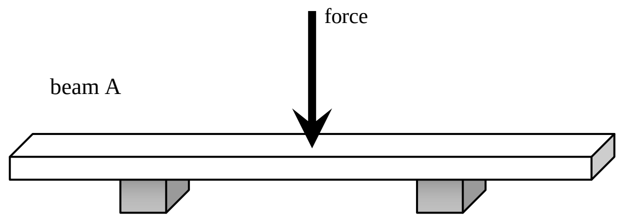
Name: ___________________________________

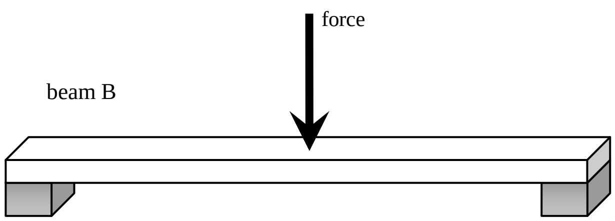
School ________________ Grade (circle one): Freshman Sophomore Junior Senior Date:

Did you take IPC (Integrated Physics and Chemistry) (circle one)? yes no What middle school did you attend? _________________

Please answer the questions as best you can. This may be material you haven't ever covered in class, so it is ok if you don't know the answers. This won't be graded, and your teachers and parents/guardians will never see the results. This is only to see if the DREAM project is effective at introducing new concepts. Please try your best.

1) Two beams are the same length, same width and same height. They are made of the same material. They are supported on two blocks as shown.
The same force is applied downward in the middle of each beam.





Which is true (circle one)?

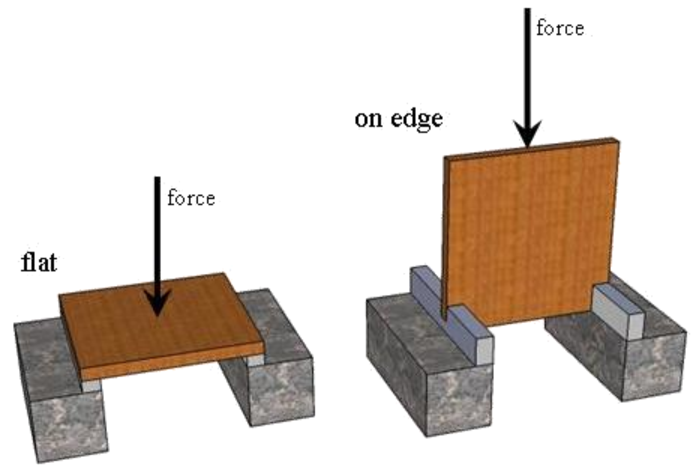
a) beam A bends more

b) beam B bends more

c) the beams bend the same amount

d) not enough information

2) Two pieces of wood are the same length, same width and same height. They are made of the same type of wood. They are supported on each end as shown.
The same force is applied downward (vertically) in the middle of each beam. The beams are glued to the posts on which they rest. They cannot flip over or rotate.



Which is true?

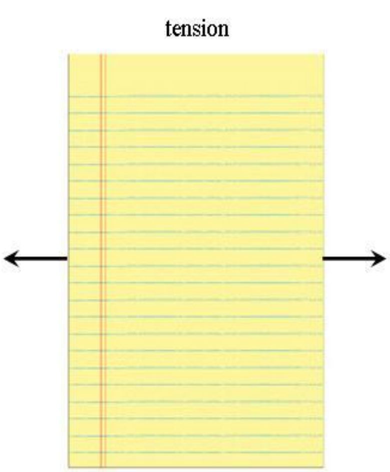
a) the "flat" board will bend more

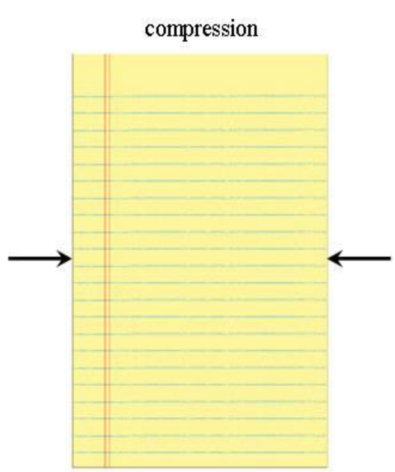
b) the board "on edge" will bend more

c) both boards will bend the same amount

d) not enough information

3) Two pieces of paper are exactly the same. One piece of paper is pulled in tension. The other is pushed in compression.





3) Which is true?

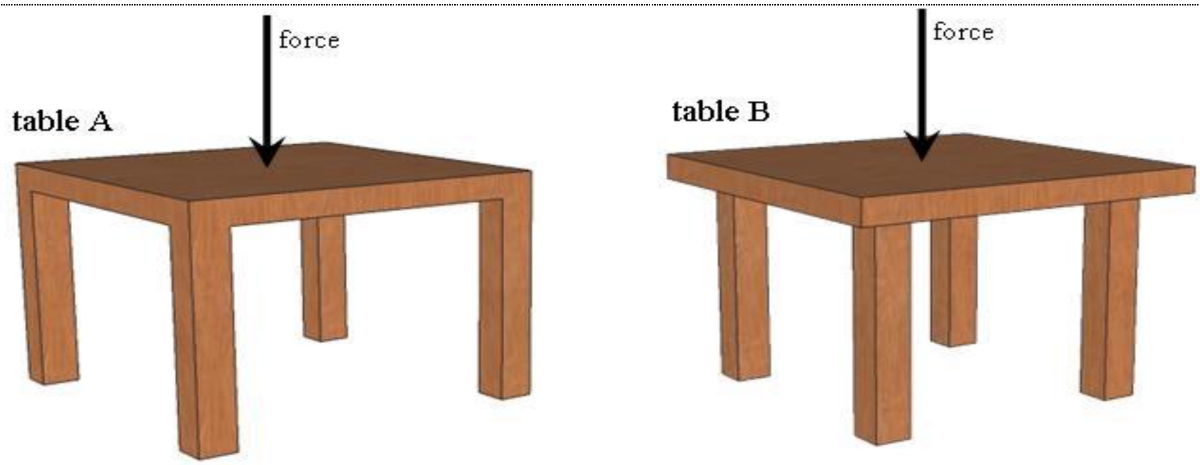
a) it is easier to pull the paper apart in tension

b) it is easier to crumple the paper in compression

c) it is equally easy to pull and crumple the paper

d) not enough information

4) Two tables are the same EXCEPT for the location of the legs.
The same force is applied downward exactly in middle of each table.



Which is true?

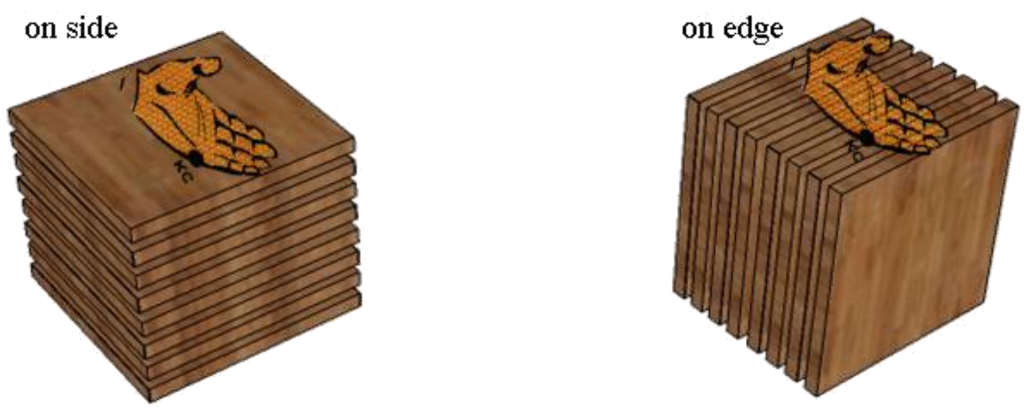
a) the top of table A bends more

b) the top of table B bends more

c) the table tops bend the same amount

d) not enough information

5) A karate expert wishes to break 8 identical boards.



Which is true?

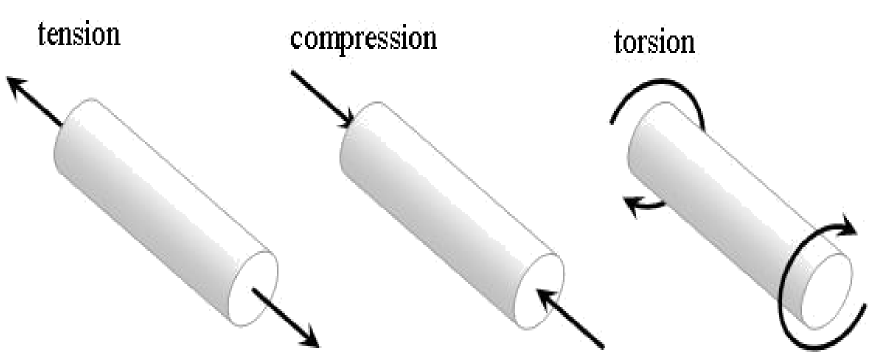
a) it will hurt more to break the boards "on side"

b) it will hurt more to break the boards "on edge"

c) both ways will hurt the same amount

d) not enough information

6) Three pieces of chalk are exactly the same.`
One piece of is pulled in tension. One is pushed in compression. One is twisted in torsion.



Which is true?

a) it is easier to pull the chalk apart in tension

b) it is easier to crush the chalk in compression

c) it is easier to break the chalk in torsion

d) all three ways of breaking the chalk are equally easy

e) not enough information

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I. Fall Semester Mini-Lecture Series

Intuition Lecture Series—Statics

This is the first part of a two part lecture series. For this first part, we seek to provide some intuition behind the concepts we are teaching. We will build on this intuition for the second part by adding equations to describe the concepts introduced in part 1.

Outline

Week 2—An introduction to Statics

Week 3—Forces and Loads part 1: compression and tension

Week 4—Forces and Loads part 2: point loads vs. distributed loads

Week 5—Statics and Stress

Week 6—Tension and Compression in Bridges

Week 7—Torsion and Shear Stress

Lecture 1: An Introduction to Statics

The world that we live in is full of examples of *static mechanics, or the study of objects that do not exhibit motion*. From the room that we sit in, to the bridges that we drive on, there are a wide variety of things that fit in this category of motionless objects.

Figure 1: The Golden Gate Bridge and the Eiffel Tower are two classic examples of objects in static equilibrium

What is statics?

The study of mechanics is made up of two parts: statics and dynamics. Dynamics is the study of anything in motion, and statics is the study of anything at rest.

Volunteer to give examples of statics?

Force

The notion of ***force*** is necessary to understand both statics and dynamics. A force is something that causes an object to accelerate.

Illustrate this point as follows:

1) First, get everyone to put their hands together. Now tell them to push their right hand with their left hand. Tell them **NOT** to resist with their right hand. Notice how the right hand moves.
2) Now tell them to do the same thing, but to resist with their right hand. Notice how the right hand doesn't move.

In the first case, the ***force*** applied by the left hand is greater than the force applied by the right hand, and so it moves the right hand. In the second case, the ***force*** applied by the left hand was equal to the force applied by the right hand, and so neither hand moved. This is extremely important for the understanding of statics: all ***forces*** balance out and so everything stays static!

Lecture 2: Forces and Loads part 1—compression and tension

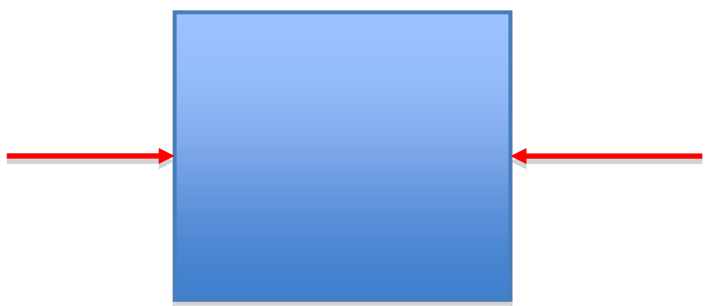
Recall: In order for an object to be static, all forces must cancel out.

Different types of forces can be put on an object in static equilibrium.

1) Tensile forces

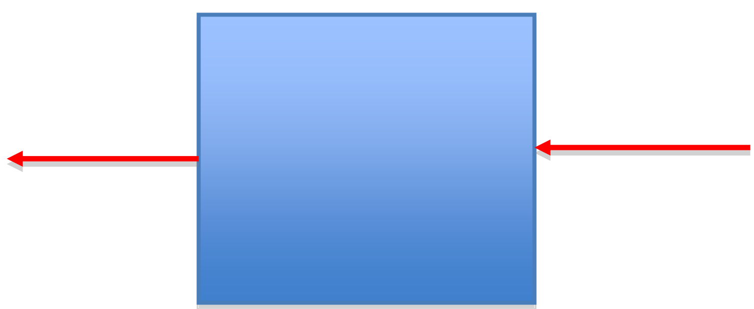
Notice how these forces are acting to pull the object apart.

2) Compressive forces



Notice how these forces act to push the box in.

Can we have a mixture of tensile and compressive forces in statics?



Notice how these forces don't cancel each other out! This is no longer a statics problem, because these forces would make the object move. Thus, for statics problems, the ***forces have to cancel out. In order for this to happen, they have to be directed opposite from one another.***

Lecture 3: Forces and Loads part 2 – Point Loads vs. Distributed loads

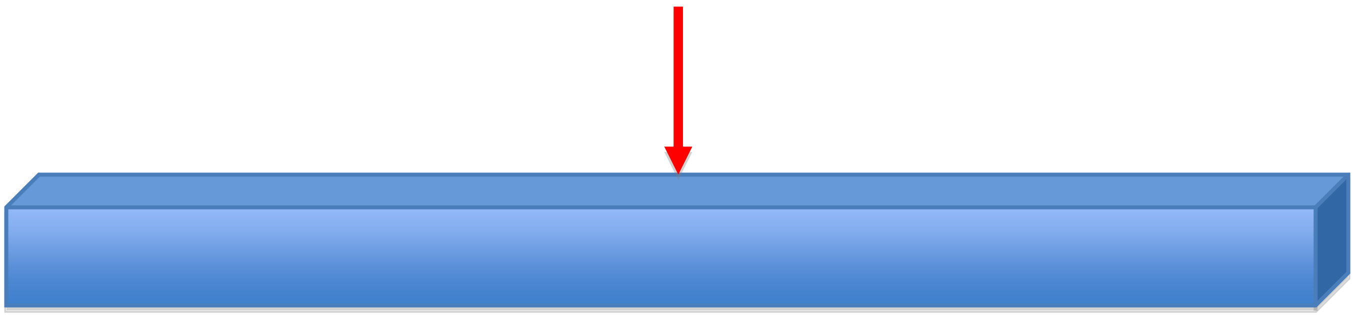
Hold up your right hand. You can use your left hand to apply a force on your right hand.

1) With the index finger of your left hand, push on your right hand
2) Now use your whole left hand to push on your right hand

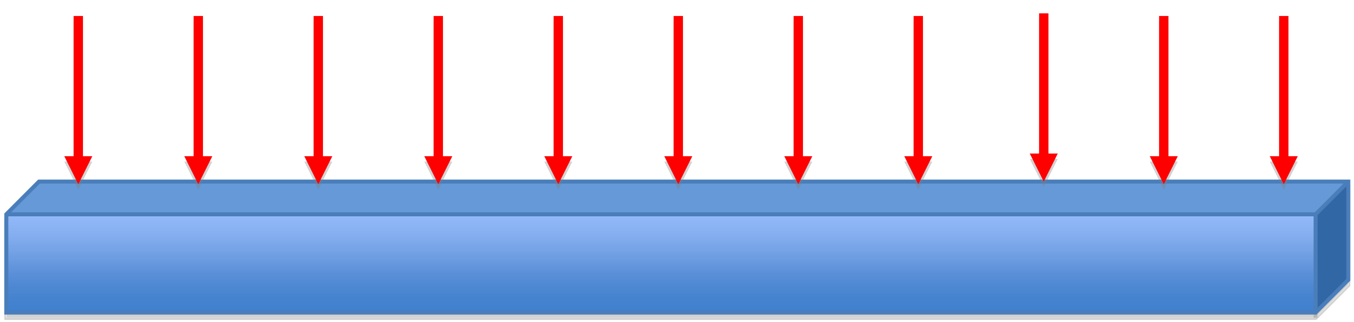
This shows that there are two ways to apply a force on an object; the first is an example of what is called a *point load*, and the second is an example of a *distributed load*. There are two ways to apply a force on an object.

Let's take this analogy one step further and consider a bridge:

First, consider a single car driving on a bridge. Because of how big the bridge is, we can approximate the force applied by the car at any point in time as a *point load:*



Next, consider a bridge that is full of gridlock traffic. We can think of the sum of the cars as having a *distributed load* effect on the bridge:



Your bridges will be tested under *point loads*, so this is all you need to worry about for the sake of the competition.

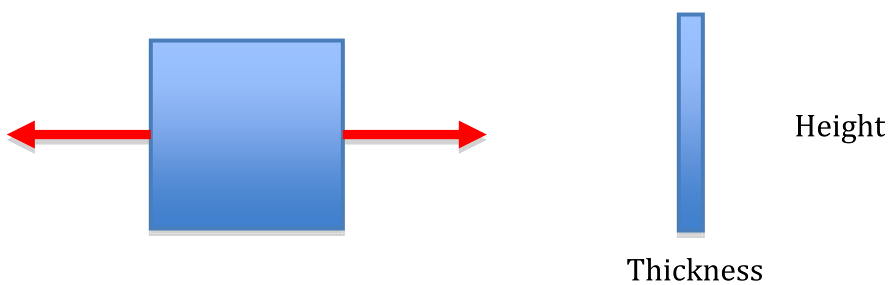
Lecture 4: Statics and Stress

Pick up a piece of paper and pull it until it is taut. Because the paper isn't moving, it is clear that it is in *static equilibrium*. Now keep pulling on the paper until the paper finally rips.

What happened? If all the forces canceled each other out, then why did the paper tear apart?

We can explain this with the idea of *stress*. Stress is defined as the perpendicular force applied to a surface divided by its cross-sectional area. In order to understand this better, consider this: if the paper had been thicker, then it would have been harder to rip. So we see that area plays a role in stress—the larger the area, the better an object is at resisting a force!

With this definition, let's go back to our example of the paper and explain what happened. As we mentioned before, the paper was in static equilibrium. However, we were applying a force over an area, which resulted in a *stress* on the paper. As we increased the amount of applied force, the *stress* on the paper increased (since the area is constant). Finally, the *stress* built up to the point where the paper ripped. We call this threshold point the yield stress.



Aside: Material Properties and Stress
Get a new piece of paper. Instead of pulling on it until it rips, try squeezing it together. Note that it was way easier to squeeze it than it was to pull it apart. This is because paper is better in tension than in compression. We call this a *material property*.

Lecture 5: Tensile and Compressive Stresses in Bridges

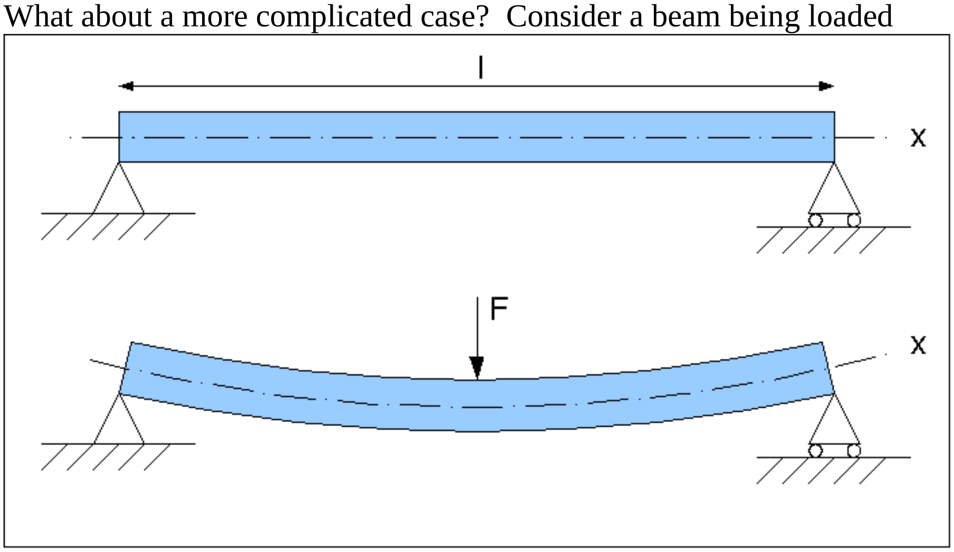
Last week, we talked about stress on an object. With this in mind, we define the following:

1) A stress caused by compressive forces is called a *compressive stress*
2) A stress caused by tensile forces is called a *tensile stress*

For example, consider the following box:

We say that such a box is undergoing a tensile stress, because it has a tensile force being applied to it.

What about a more complicated case? Consider a beam being loaded



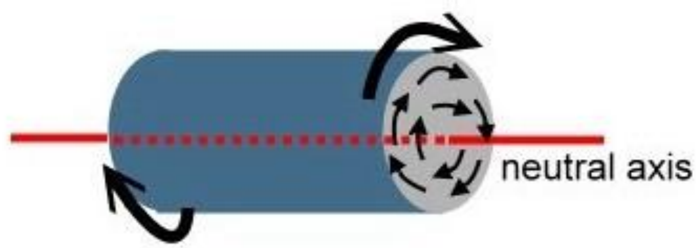
Notice that the top part of the beam is being squeezed together (under compression) and the bottom part of the beam is being pulled apart (in tension). Thus, we can say that the top part of the beam is undergoing compressive stresses, and the bottom part of the beam is undergoing tensile stresses.

Lecture 6: Shear Stress Torsional Stress

Last week we talked about how applying tensile and compressive forces to objects results in tensile and compressive stress on that object, respectively.

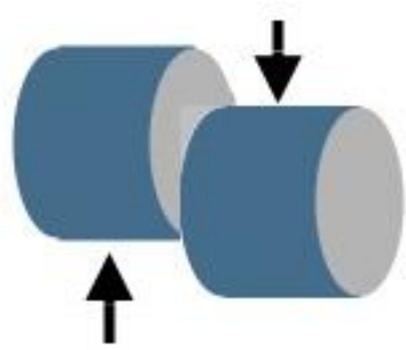
Now we consider a different type of stress that is known as torsion, or *stress of twisting.*

Note that this is an object that is in static equilibrium: all forces are canceling out. However, the forces are imposing a stress on the object. Consider the figure below:



The object is being twisted. As an example of torsional failure, consider breaking a piece of chalk by twisting it.

Last, we will talk about shear stress. This is an important type of stress *that is parallel to the material's cross sectional area.* Consider the figure below.



Wrap the lecture up by asking the students to give an example of each type of stress (tensile, compressive, torsional, and shear).

II. Spring Semester Mini-Lecture Series

In-Depth Lecture Series—Statics

This is the second part of a two part lecture series. We will build on the intuition from semester 1 by adding equations to describe the concepts introduced in the first semester of this statics course.

Outline

Week 1—Units/ Understanding Forces through Units

Week 2—Introduction to Stresses

Week 3—Tensile Stress vs shear stress; relevant areas

Week 4—Bending Stress: combination of shear and tension

Week 5—Effect of Length/ thickness/location of force on induced stress

Week 6—Trusses

Appendix C

Lecture 1- Units/ Intro to Forces

This semester, you will be designing cantilevers to support a load. The goal is to make a cantilever that is strong enough to withstand a force applied at the end, but also to maximize the length of the cantilever. In order to understand how to make a strong cantilever, it is important to understand how forces work. A force is something that makes an object accelerate. But how can we measure this? Can a force be compared to a mile?

We measure the world around us in *units*. Units are the way that we distinguish time from length, length from acceleration, and so on. For example, it is not fair to compare 4 apples to 3 seconds, because they do not share the same units. Thus, we measure everything in units, and certain basic units serve to build more complicated units. The basic units that we will consider are length, mass, and time. These units will be used to understand more complicated units; force is an example of something that is measured as a combination of these basic units.

The equation we use to determine a force is $Force = mass \times accleration$. Mass is often measured in terms of the unit pound-mass (lb_m) or kilograms (kg). Acceleration is measured in units of length per time squared, for example feet/seconds^2. Notice that the units of acceleration are made up of the basic units of length and time. The units of force are $\frac{Mass \times length}{time^2}$, which we get by multiplying the units of mass by the units of acceleration:

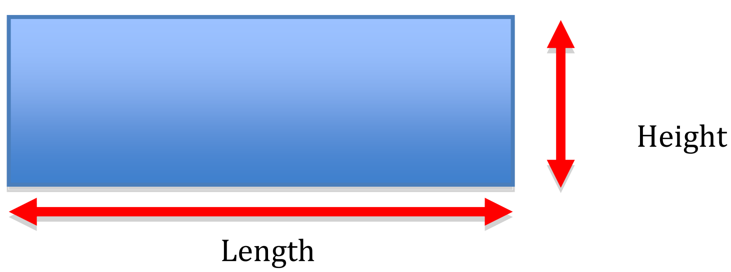
$$Force = mass \times accleration$$

$$Force = mass \times \frac{length}{time^2}$$

Examples of units of force include pound-force (lb_f), which we often refer to as just pounds, and Newtons (N).

Next week, we will learn about stress, which is defined as force per area. Area is measured in units of length^2, for example square inches or square miles.

For example, to calculate the area of a rectangle, we multiply the length by the height.



If there's time: talk about the fact that L*H is equivalent to adding L up H times. Use it as an intuitive understanding for the area as a summation of lengths.

Lecture 2: Introduction to Stresses

As we mentioned last semester, an object in static equilibrium is one in which the forces cancel out on all sides:

In the picture above, the rectangle is not moving because the force F is exactly canceled out on either end of the box.

Now consider the following example: you pull on a piece of paper on either side so that it is in static equilibrium (i.e. you pull with a force of equal magnitude on either side). If you pull hard enough, the paper will rip. How did this happen? The forces exactly canceled each other out, so the net force was zero. How then did the paper break?

The answer is that the paper underwent too much *stress*, causing it to rip. Just like in the paper example, the cantilever beams that you build will undergo stress. Stress is defined as force applied over an area:

$$Stress = \frac{Force}{Area}$$

Thus, it is the stress that is making the paper rip. After Lecture 1, it seems appropriate to check the units of stress. They are

$$Stress = \frac{Force}{Area}$$

$$Stress = \frac{\left(mass \times \frac{length}{time^2}\right)}{length^2}$$

$$Stress = \frac{mass}{length \times time^2}$$

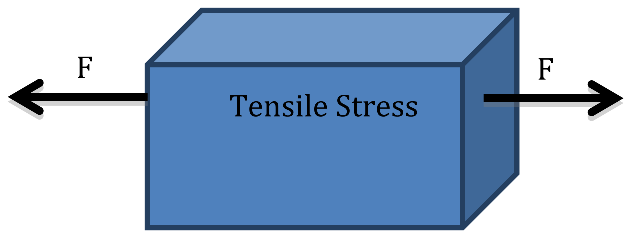
So stress is a force applied per unit area on an object, and it is this stress that is responsible for objects breaking. Lets use this equation to get a feel for the relationship that force and area have on stress. Notice that if we increase the force, stress increases. This makes sense: we'd expect that as we pull harder on the paper, it is more likely to rip. By contrast, if we increase the area, the stress goes down. This makes sense too: if we made the paper thicker, then it would take more force to rip it. Thus, the definition of stress agrees with our intuition about the strength of materials.

Appendix C

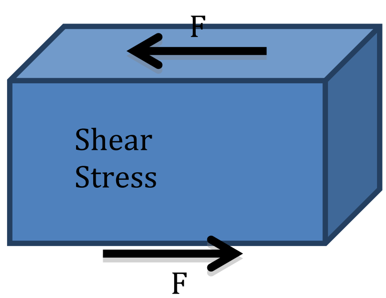
Lecture 3: Tensile Stress vs Shear Stress and Relevant Areas

Last week, we learned about stress, which is a force applied over an area. Recall that we 2 . There are many different types of stresses; today we will discuss tensile stress and shear stress.

Think of the example from last week of a paper being pulled on both sides in opposite directions. The paper is in tension – it is experiencing tensile stress. Tensile stress is a stress state caused by pulling forces (it is the opposite of compression). An example of a member in tension would be a rope during a game of tug-of-war. This type of stress, applied to two sections of material on opposite sides, can cause the material to pull apart or elongate.



Shear stress is a stress that is applied parallel to the surface of a material. Shear forces can be thought of as sliding forces, which tend to change the shape of a material. Many examples of shear can be seen in nature, like landslides (mud and rocks sliding down the side of a mountain) and earthquakes (two of the earth's plates sliding against each other).



xarea, but what is the area in this equation? When determining stresses, we are concerned with the cross sectional area that the force is applied to. In the case of the examples drawn above, where a force is applied to the face of a box, this means we would need to calculate the area of that face. (NOTE: Work out an example problem calculating the area associated with shear and tensile stress to further explain this concept.)