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Designing a Scalable Statics Project for a First-Year Mechanical Engineering Course

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Designing a Scalable Statics Project for a First-Year Mechanical Engineering Course

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***Abstract* - A project, presented in this paper, is designed for a freshman-level class to introduce the mechanical engineering subject of statics in four weeks. The project is designed to be suitable for a small or medium sized class (less than 50 students) and also for a larger class (more than 200 students). The project was tested during the fall semester of 2016 on a class of 48 students. It was successfully scaled to a class of 221 students during the spring semester of 2017. The project is presented in this paper along with a discussion of the resources (materials) and personnel (faculty and graduate teaching assistants) required. The statics project is considered simple to implement at a low-cost but effective and appreciated by the students. Continuous improvements to the project are made based on faculty observations and assessments, as well as a survey administered to the students.**

Index Terms – statics, truss, project.

INTRODUCTION

A two credit-hour, first-year course is offered in our Mechanical Engineering Department. It is a pre-requisite for core mechanical engineering courses including mechanical design, statics, kinematics, dynamics, thermodynamics, fluid mechanics, and heat transfer. The purpose of this course is to give students a general understanding of the broad range of technical areas and applications specific to the mechanical engineering profession. To address the broad range of technical areas, the students work on four design-related projects throughout the semester: computer-aided design, design of structures, mechanism design, and thermal analysis.

Similar freshman level introductory courses are offered in engineering educational programs and are subject of numerous notable publications. Recent publications seem to agree that projects and hands-on-activities are a very important aspect of freshman engineering courses. Gaines et. al. [1] presented an introduction to engineering course with hands-on engineering design projects for several engineering disciplines. Hargather [2] presented and integrated lecture-lab course to replace traditional free-standing lecture and lab courses. Swenson [3] wrote about freshman engineering course where students self-defined sub-problems related to robotics with focus on innovation and creativity. Gipson et. al. [4] constructed freshman courses using learner-centered, experiential, and project based learning approaches. Alford [5] discussed the need for socially conscious project that can awaken the passions of freshman students who expect to be the new innovators. Goodrich and McWilliams [6] used two projects: a Lego Robotics project and a flotation platform project to introduce freshman students to the engineering design process, working with uncertainty, and improving teaming/communication skills. Books are also available to support the freshman level introductory courses [7, 8, and 9].

Kits are commercially available in abundance and several have been reviewed. However, these are found highly task-specific and not customizable. They can also be very costly when applied to a large class desiring hands-on experience.

Some course learning outcomes for the two credit freshman course are stated as follows and the project discussed here relates to one part of outcome 1. It also relates to outcomes 2 and 3.

1. Explain concepts in mechanical design, forces and stresses, engineering materials, motion and power transmission, and thermal and energy systems.
2. Develop problem-solving and communications skills.
3. Function as a team on group projects.

In this course, one weekly 50-minute lecture is offered by the instructors or invited mechanical engineering experts. It is followed by a 100-minute weekly lab where students complete team-oriented and hands-on activities related to the topics covered in the lecture. This lecture/lab format was adopted to help students experience practical applications and to improve the student's commitment to learning.

Presented in this paper is one portion of the course which consists of a statics project designed to give students a preliminary understanding of designing structures. The project's duration is one fourth of a semester. Students work in teams of two to design a truss which can bear the highest possible load within given space and materials constraints. The students conduct research and brainstorm different truss designs. Once they select a design, they generate a set of equations to model the truss, solve these equations using MATLAB, and determine the load in each of the truss' members. Finally, they fabricate their prototypes using very simple materials and subject the prototypes to testing. They determine the highest load the truss can bear. More importantly, they compare the location of the failure in the physical prototype to the location of the highest forces in their calculations and make a connection between the calculate forces and the prototype failure.

The project presented in this paper is highly scalable and can be implemented in a large class at a low cost. Its burden on teaching assistants is light relative to a previous project used in this course. It can be easily reproduced in any lab with desks, computers, and Internet access. The startup cost of the project (buying the tools) and the cost of the disposable materials are manageable as these are readily available and reasonably priced.

Students find the project's deliverables achievable and work hard to meet them while learning concepts related to statics that would prepare them to taking core courses later in the mechanical engineering curriculum.

PROJECT GOALS

The project presented here is intended to teach the freshman students basic concepts in statics. They learn about forces acting on structural components within a truss structure. Students learn to set-up simple Free-Body Diagrams (FBD) and solve systems of equations using MATLAB. The project also helps the students attain problem solving and communication skills as they work together in teams of two to generate a unique design. It also helps the students understand the value of assembly drawings and a bill of materials to manufacturing an assembly.

The goal of the project is to give students an introduction to the statics area of mechanical engineering and give them skills needed for future more detailed courses in the mechanical engineering curriculum. The project helps achieve this goal, as it asks students to calculate stresses in a truss, build the truss, apply loading on it, and check if the truss physically fails in an area where the highest forces were calculated. It relates to course learning outcomes 1 (partially), 2, and 3 which were stated above.

PROJECT DESCRIPTION

Two 50-minute lectures are offered to cover forces in structures and are based on Wickert and Lewis [9]. The lectures address the summation of forces should be equal to zero for a body in equilibrium. They cover decomposition of a force into its orthogonal components. The lectures address truss elements and their ability to handle tension or compression but inability to handle moments. The method of joints is then explained in the context of a truss. Lecture slides are offered for download through the class' Black Board eLearning page. The students are also asked to review the slides and read the chapter in the book before coming to the lab.

An additional lecture on the use of MATLAB is also given. This helps the students learn to convert a system of n-equations and n-unknowns into a matrix that can be inverted in MATLAB to obtain values for the unknowns.

Four 100-minute labs follow the lectures where the overall project's requirements are divided by the instructor into weekly deliverables. The students are paired into teams of two. Each team is given a computer and is asked to submit the weekly deliverable after the lab. One graduate teaching assistant supports up to 12 teams (24 students) during the labs.

In the labs, the students are initially given a simple three-member truss as shown in Fig. 1.They are asked to apply the method of joints and write a total of six equations with six unknowns for the three joints in Cartesian coordinates. The students are asked to convert the equations into a matrix operation, invert the matrix, and calculate the six unknowns in MATLAB.

The forces acting within the simple geometry used here (Fig. 1) allows the students to understand and apply the method of joints. The majority of the students are able to generate free body diagrams for the three joints, write the equations for the forces in Cartesian coordinates, convert the equations to a matrix, and use MATLAB to solve the matrix based on a force F = 50 grams.

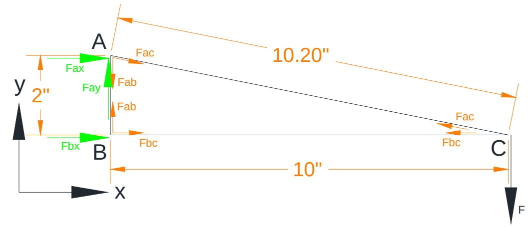


FIGURE 1
GEOMETRY AND FORCES IN THE SIMPLE TRUSS.

While this work may seem trivial for individuals who completed a statics class, it is quite challenging for a team of two freshman students working together for the first time. Students with different capabilities learn from one another as the teaching assistant supports them during the lab and reminds them of the lecture materials.

While many programs are available to evaluate a truss, a web based simple program is introduced to the students [10]. The students are asked to create their truss in this program and re-calculate the forces in all their members (Fig. 2).

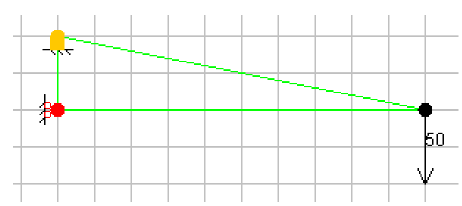


FIGURE 2
SIMPLE TRUSS CALCULATION.

Having calculated forces from their own calculations and also from the web based program, the students are asked to compare the forces. They are taught that a matching comparison would qualify the web based program for use in their next steps.

The students are offered disposable supplies in a bag as shown in Fig 3 (A). These consist of 15 plastic straws which will serve as truss members, 20 rivets (1/8" diameter) and washers which will serve as pin joints, and a single 12" long string. They are also offered lab tools: a scissors, a 1/8" hole-punch, and a rivet gun as shown in Fig. 3 (B).

The properties of the straws are pointed out in the lecture. Specifically, straws can tolerate high tension but very little compression. In the lab, the students find that a 50 gram load applied at the end of the arm can yield high tension in one member of the truss and high compression in another.

(A) DISPOSABLE SUPPLIES (B) TOOLS

FIGURE 3
SUPPLIES AND TOOLS NEEDED.

Before doing any physical work with the given materials, the students are asked to modify the design of the crane arm by adding nodes and members. Up to seven (7) nodes are allowed in total for the two-dimensional geometry.

They start researching (using the Internet) different designs that would yield the strongest possible crane within the 10”x2” given overall size. For each design considered, they calculate (using the web based program) the loads on all their truss members. Steps of the engineering design process (Oakes and Leone [8]) are implemented here as the students are asked to define their goals, research, brain storm, calculate, communicate, and make decisions. Final solutions provided by the student teams vary widely even though they work in the same lab and discuss the designs inside and outside the lab.

The students are introduced to AutoCAD (www.autodesk.com) in this activity as a three dimensional sketching tool. A presentation is given in the lecture to show basic AutoCAD commands and a detailed tutorial is provided in the lab. The students create a three dimensional line sketch of their design (Fig. 4) and use the sketch to calculate the actual lengths of all their truss members.

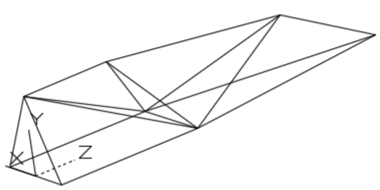
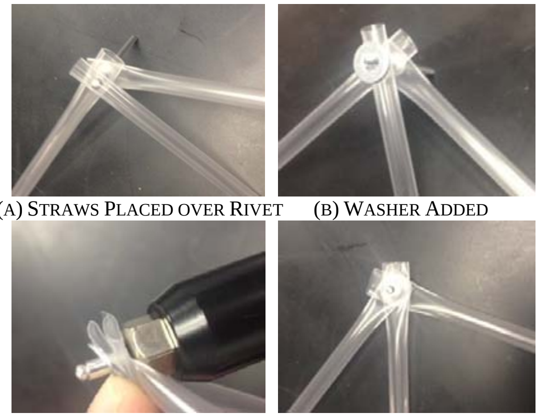


FIGURE 4
THREE DIMENSIONAL TRUSS.

The students are asked to label the members of the truss and generate a bill of materials. They are asked to cut the straws and label them according to the dimensions shown in the bill of materials. Since the use of a rivet gun is illustrated in the lecture (Fig. 5), most students use the rivet gun with minimal help from the professor or the graduate teaching assistant. However, some student request additional help.

Students can get very disappointed when they make a mistake: cut a straw or add a rivet in the wrong place, only to learn there is no “undo” button in the physical world. The students are instructed to measure twice and cut once. They are also repeatedly reminded to count the number of members at each joint in their CAD design and confirm the correct straws are included before applying the rivet.



(A) STRAWS PLACED OVER RIVET (B) WASHER ADDED

(C) RIVET APPLIED (D) FINAL JOINT

FIGURE 5
RIVETING ILLUSTRATIONS.

The building process, as captured by one of the students and posted on a social media site, is shown in Fig. 6. The labels on the straws shown in these images are per the student’s bill of materials while the design is per the line drawing generated by the students in AutoCAD.

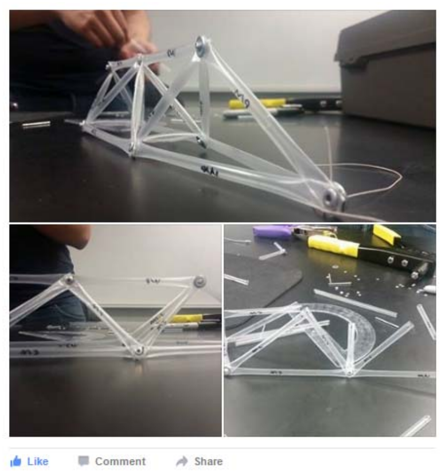


FIGURE 6
PROCESS OF MAKING THE TRUSS.

Finally, testing the truss is performed using a clip attached onto a trifold foam board and a spring scale. The scale is connected to the string as shown in Fig. 7. It is pulled by hand and a measurement is recorded when at least one member or joint is displaced approximately ½” out of its original position.

More importantly, the students are asked to evaluate the location of the failure and compare the location in their physical prototype to the location of maximum loading in their truss calculations. The intent, here, is to help students understand the physical meaning of their calculation and connecting the area of failure due to high compression in a straw to a member experiencing high compression in the truss calculations.

FIGURE 7
TESTING.

The students are asked to create reports at the end of the each lab session for grading. These reports include scans of hand calculations, copies of MATLAB scripts, screen prints of their iterative designs using the web based program, screen prints of CAD designs, and pictures of their prototype. They are also asked to make recommendations for future designs.

PROJECT RESOURCES AND SUPPLIES

It is found that the physical presence of one graduate teaching assistant is needed in the labs for each 24 students. This allows the teaching assistant to be helpful to the students and the instructor to manage special circumstances that can occur during activities without disrupting the lab.

The teaching assistant’s time is also needed for office hours and grading. It is preferred to have one teaching assistant working 20 hours per week for each 70 students (or one teaching assistant working 10 hours per week for every 35 students). If the ratio of students to teaching assistants is more than 70, delay in homework grading is noticed. The delay can become intolerable when the ratio approaches 80.

The following supplies are required to execute the project for a class of 240 students. The supplies presented here are based on dividing the class into 5 sections of 48 students.

A tool set is shown in Fig. 8 and consists of a rivet gun that can support 1/8” rivets, a 1/8” hole-punch, and a scissors. The class described in this paper allocates one set of tools for every team of two students on one section. A total of 24 sets are needed, as 24 teams work simultaneously in one lab. Two extra sets are also needed as spares.

FIGURE 8
TOOL SET: RIVET GUN, HOLE PUNCH, AND SCISSORS.

Additional supplies are needed for the lab as shown in Fig. 9. A 36”x48” foam trifold board is needed for testing. A hook is attached to the foam board to hold a simple clip that would hold the truss. Three scales are needed with different ranges. VWR® Linear Spring Scales with 10g, 25g, and 100g range were used in this projects. An extra set of these supplies is also needed as spares.

(A) FOAM BOARD (B) SCALE
FIGURE 9
TOOL SET: RIVET GUN, HOLE PUNCH, AND SCISSORS.

The disposable supplies needed include straws, washers, and rivets. 15 drinking plastic straws (non-flexible) are needed per each team. A total of 1800 straws are needed for the whole class with 240 students. It is recommended to pre-purchase a sample before buying the straws to make sure the ones used in the project do not easily break and split when squeezed or handled.

2600 washers 1/8” diameter and 2600 rivets 1/8” diameter are also needed. These will give each team of two students 20 washers and 20 rivets while leaving a few extras.

Additionally, a Button/Carpet Extra Strong Thread is used at the end of the crane arm. A single 50 yard reel is sufficient for the class of 240 students.

Finally, 120 gallon-size zip baggies are needed. The washers, rivets, thread, and straws can be pre-packaged in these baggies. Having the supplies pre-organized allows for quick setup when classes are given back-to-back in the same room. They also allow for students to keep their supplies together and take them to office hours in case they do not finish the work during the lab time.

PREVIOUS VERSION OF THE PROJECT

A previous version of this project was used in the Spring of 2016. In this previous version, the truss represented a bridge that was pinned on both ends as shown in Fig. 10. In this previous version, the students applied similar calculations and tools as those described above. However, they were asked to analyze and calculate the forces in every member of their final truss. They generated and solved large matrices which were difficult to most freshman students and required overwhelming support from the instructors and teaching assistants. The revised project only required manual analysis of the three member truss where the matrix includes 6 equations and 6 unknowns. The freshman students were able to accomplish these calculations with reasonable support.

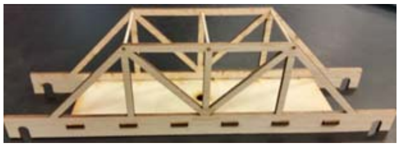


FIGURE 10
BRIDGE.

The students were also given a three dimensional CAD model of the rectangular base of the bridge. They were asked to model their truss structure in SolidWorks above the base. They were also asked to perform a finite element analysis of the structure in SolidWorks. This portion of the activity was removed from the project because the use of SolidWorks is already incorporated in another segment of this freshman course. Finite element modeling was also removed and reserved for more advanced engineering classes.

Upon completion of the SolidWorks drawings, the graduate teaching assistant collected all the models, processed them and cut two pieces of balsa wood for each team using a laser cutter. The cut pieces were given back to the students who assembled the bridge using glue. While the capability to laser cut remains available, it requires a severe time commitment and parts management from the teaching assistants when over 200 students were enrolled in the class. This was eliminated when using the straw bridge which was entirely fabricated by the students themselves in the lab.

Finally, the destructive testing of the balsa wood bridge required the use of safety glasses and gloves in the lab and resulted in a very dirty lab, especially when two labs were scheduled in the studio back-to-back. Using the straw crane arm, eliminated this issue and resulted in a project that can be easily scalable to a large class.

ASSESSMENT AND GOAL ATTAINMENT

The overall assessment in this segment of the course was based on both, the lab teamwork and the individual performance on the exam. Direct assessment of the teamwork was performed by grading the lab deliverables according to an established rubric. Observations related to the student's teamwork in the lab were also recorded. Exams were provided to evaluate the individual student's understanding of the concepts offered.

Most students demonstrated competency in calculating the forces. Some students exceeded expectations by provided well-researched explanations of their designs. A few did not meet expectations and showed weakness in understanding the project even with the instructor's and teaching assistant's help. Weakness was mainly exhibited in converting the hand calculations into a MATLAB script. The project's simplicity, however, allowed most teams to attain the goals set forth. Specifically, most students demonstrated understanding of the requirements of the project and did well on the exams.

STUDENT FEEDBACK

The students showed a high level of engagement as they worked on this activity. They used the lab time and some office hours (when needed) to complete their designs. At the end of the course, they provided statements as part of a survey.

A student appreciated the engineering value of the statics project and wrote: "It was a great chance to learn how to work in CAD, how to create free body diagrams, how to create and design simple truss structure with the materials given, and a great experience in actually building a truss structure based on our design and calculations." Another student captured the goal of the project and wrote: "This activity was very useful for understanding Statics concepts that will be needed in future MECH courses."

In the survey, the students were also asked to respond to specific statements related to their perception of the project's impact on learning.

- Spring 2016 (S'16) was the semester where the previous version of the project was used and a balsa wood bridge was built. It included 237 students. 64% of the students completed the survey.
- Fall 2016 (F'16) was the first semester where the new project with the straw crane arm was uses. It included only 48 students, 46% of the students completed the survey.
- Spring 2017 (S'17) also included the straw crane arm and included 221 students. 69% of the students completed the survey.

The student's answer to the following questions were compiled and shown in Fig. 11 (using a Likert scale [11]) during the three consequent semesters.

- **Design Process**: This activity helped me better understand aspects of the design process including engineering analysis, prototype development and documentation using engineering drawings.
- **Statics**: After working on this activity, I understand how to perform simple static analysis on load bearing structures using MATLAB.
- **Free Body Diagram (FBD)**: I am comfortable setting up a free body diagram and the equations of static equilibrium by hand.

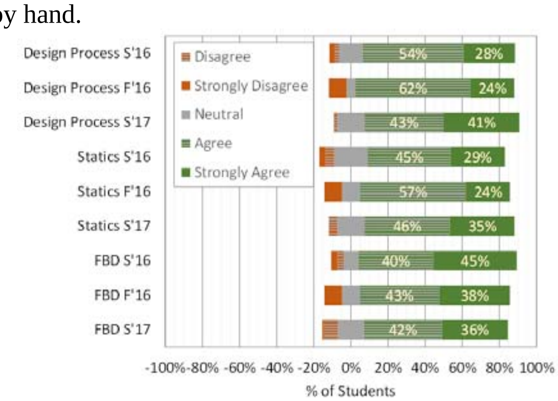


FIGURE 11
STUDENT RESPONSE TO SURVEY QUESTIONS ABOUT LEARNING.

Based on this figure, the students considered this statics activity helpful in improving their understanding of the design process, statics, and free body diagrams. Only a few students disagreed or strongly disagreed with these statements.

Comparing student's response regarding the previous version of the project (S'16) to the new project in subsequent semesters (F'16 and S'17) indicates an improvement in understanding the engineering design process. An improvement is also indicated on the student's ability to perform simple static analysis. However, there is a decline in their perceived ability to create free body diagrams and generate the equations. This decline is likely due to the simplification of the requirement to analyze, using free body diagrams, the complete truss design (S'16) to only the three member arm (F'16 and S'17). In general, all answers remain highly skewed to the positive in Fig. 11 and the project is considered successful. It will, however, be subject of continuous improvement in the future.

Questions related to motivation were based on two aspects. We considered the student's enjoyment, as students could be motivated if they enjoyed the activity. We also considered value, as students would continue working until the goals were met if they saw value in their work [12, 13]. We believe that the following statements, together, would provide an indication of the motivation albeit not a complete one. In future iterations of the survey, we may include more questions to get a better indication the student's motivation. The statements given in our survey were:

- **Enjoyment**: I enjoyed working on this activity.
- **Value**: The concepts I learned while working on this activity will be of value to me.

Regarding 'Enjoyment,' as can be seen from Fig. 12 and considering all three semesters more than 69%, of the students enjoyed working on the project (sum of 'Agree' and 'Strongly Agree' categories). Considering the change in student response from the Spring 2016 to Spring 2017 semesters, we see that the percentage of students enjoying the Statics project increased by 14% when the revised new was implemented.

Regarding 'Value,' as can also be seen from Fig. 12 and considering all three semesters more than 84% of the students found the Statics project valuable. Considering the student responses from Spring 2016 to Spring 2017 semesters, we see that Statics increased by 5%.

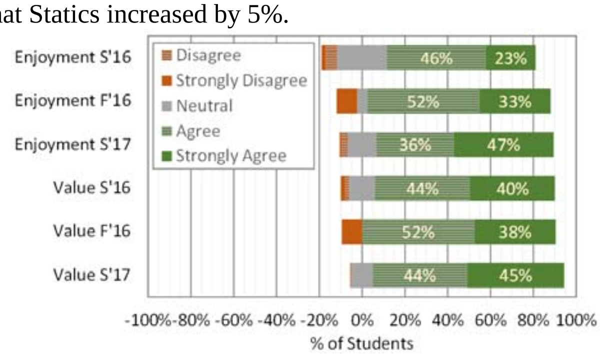


FIGURE 12
STUDENT RESPONSE TO SURVEY QUESTIONS ABOUT ENJOYMENT AND VALUE.

CONCLUSIONS

A statics project is presented for a freshman level class in mechanical engineering. It is designed to be scalable from a small or medium sized class (e.g., 50 students or less) and also for a larger class (e.g., 250 students or more). The project was successfully tested during the fall of 2016 on a class of 48 students. It was successfully scaled to a class of 221 students during the spring of 2017. The project is successful but is subject to continuous improvements based on faculty observations, assessments, as well as a survey administered to the students.

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REFERENCES

[1] Gaines, J., et al., 2014, "Introduction to Engineering Design: Piloting Design Projects for the First Year Engineering Experience," *6th First Year Engineering Experience (FYEE) Conference*, August 7-8, College Station, TX.

[2] Hargather, C. Z., 2014, "Re-design of an Inter-Disciplinary First-Year Introduction to Engineering Course Focusing on Active Learning and Technology in the Classroom," *6th First Year Engineering Experience (FYEE) Conference*, August 7 – 8, College Station, TX.

[3] Swenson J. and Danahy E., 2014, "Analysis of Feature Development during Iterative Design in First Year Engineering Course," *6th First Year Engineering Experience (FYEE) Conference*, August 7 – 8, College Station, TX.

[4] Gipson, K., et al., 2015, "Development and Implementation of a First-year Engineering Experience," *7th First Year Engineering Experience (FYEE) Conference*, August 2 – 4, 2015, Blacksburg, VA.

[5] Alford, V. G., 2016, "A Project Centered Course for Socially Conscious Engineering Freshman," *First Year Engineering Experience (FYEE) Conference*, July 31 – August 2, Columbus, OH.

[6] Goodrich, V. E. and McWilliams, L. H., 2016, "Implementation of a Flotation Platform Project for a First-Year Engineering Project-Based Course," *ASEE 123rd Annual Conference and Exhibition*, New Orleans, LA, June 26-29.

[7] Eggert, R. J., 2010, "Engineering Design," Second Edition, High Peak Press, ISBN 978-0-615-31938-4.

[8] Oakes, W. C. and Leone L. L., 2015, Engineering Your Future, Eighth Edition, Oxford University Press, ISBN 978-0-19-934801-5.

[9] Wickert J. and Lewis K., 2015, "An Introduction to Mechanical Engineering," Fourth Edition, Chapter 4, pp 116-170, Cengage Learning, ISBN 978-1-305-63513-5.

[10] Bridge Designer, Johns Hopkins University, http://pages.jh.edu/~virtlab/bridge/truss.htm.

[11] Robbins, N. B. and Heiberger, R. M., 2011, "Plotting Likert and Other Rating Scales," *Joint Statistical Meeting*, Section on Survey Research Methods.

[12] Dunn, J. S., 2008, "Assessing and Improving Student Motivation," *Center for Teaching Excellence*, United States Military Academy, West Point, NY.

[13] Pintrich, P. R. and Schunk, D. H., 2002, Motivation in Education, 2nd Edition, ISBN-13: 978-0130160096.

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