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Abstract

What is Engineering? is a course designed by Johns Hopkins University, and in partnership with The Mathematics, Engineering, and Science Achievement (MESA) Program, conducted at multiple sites throughout California. This course is designed to introduce multiple engineering topics to high school juniors and seniors. The MESA Schools Program (MSP) provides academic development for educationally disadvantaged pre-college students so they will succeed in math and science and go on to attain baccalaureate degrees in math-based majors. Through an approach that includes hands-on activities, school site teacher support, leadership skills, career & college exploration, and parent programming, MSP students are empowered to excel. The goal of the Johns Hopkins/MESA collaboration is to attract students to major in engineering and ultimately retain them in the discipline. Students have the potential of earning three units of Johns Hopkins credit after completing this intensive four-week summer course. This paper will focus on the findings developed from the classes held on the University of the Pacific site. A description of the objectives and design of the course, student feedback, and recommendations for future direction for improving their impact on student learning and appreciation of engineering are reported.

Introduction

Course Origin

What is Engineering? originated as an *Introduction to Engineering* class offered to first-semester freshmen at Johns Hopkins University [JHU]. Motivated primarily by the shortage of students entering STEM subjects, where fewer than 20,000 science and engineering graduates are produced annually[1], JHU decided to adapt the course into a summer program aimed at rising high school juniors and seniors as well as incoming college freshmen. The *What is Engineering?* course provides a challenging and rewarding academic experience for students who have an interest in math and science and want to explore engineering and its disciplines with the possibility of receiving college credit from JHU. As a summer course, the class is an intensive four-week experience where students actively participate in hands-on team activities including laboratory experiments and virtual internet-based simulations while attending college-level lectures related to these activities. Field trips to local companies that employ engineers and informational sessions on college and career choices are also integrated into the course schedule. In short, the curriculum links math, science, and engineering concepts to

practical problems as a means of teaching students the essential problem-solving skills required to be a successful engineer.

Course Expansion

In the summer of 2006, *What is Engineering?* expanded to various universities in California when the Mathematics, Engineering, and Science Achievement (MESA) Program entered into a collaboration with JHU (the partnership is described later in the next section). The expansion involved the addition of four MESA sites located on the following university campuses: CSU Fullerton, CSU Long Beach, UC Santa Barbara, and the University of the Pacific. Typically, each site provided its own staffing: the MESA site Director served as program administrator, an instructor drawn from each School of Engineering served as Faculty; a local high school MESA Advisor served as teaching assistant; and a currently enrolled undergraduate engineering student served as a tutor, available to the students for additional help outside of class. In the summer of 2007, the same universities were involved with the addition of two non-MESA supported California sites at California Lutheran University and Pasadena City College. During summer 2007, classes were also conducted at non-MESA supported sites on the east coast, including the Homewood campus of JHU, JHU Montgomery County, and Harrisburg (Pa) SciTech High School. All of the sites named above will be participating again during the summer of 2008 with the hope of expanding to additional locations in the coming years.

MESA and MSP

Founded in 1970, the Mathematics, Engineering, & Science Achievement program, administered by the University of California, is one of the country's most successful programs of its kind. Providing academic support for thousands of educationally disadvantaged students across the state, MESA serves students through three distinct programs: MSP, MCCP, and MEP. The MESA School Program (MSP) works with 6-12th grade students in the most underperforming schools so that they will excel academically, going on to earn their baccalaureate degrees in science, engineering, computer science, and other math-based fields. The MESA Community College Program (MCCP) assists community college students so that they can transfer to four-year institutions as majors in math-based fields. The MESA Engineering Program (MEP) helps students at major California universities to attain degrees in engineering and computer science.

Specific MESA services offered to all participants include: individualized academic planning, community building, learning opportunities, study skills training, peer group learning, mentoring, career exploration, professional development, and transfer assistance. Furthermore, MESA provides rigorous academic development that offers pre-college students math and science curriculum based on the California Math and Science Standards, while creating parent programming and teacher development opportunities. Special programming targeting community college and university engineering students includes orientation classes, study center space, student tracking, retention services, and incentive awards.

MESA works closely with industry partners, the University of California, the California State University system, California Community Colleges, the Association of Independent Colleges

and Universities, the California Department of Education, school districts, and individual schools. Recognizing the program's success in producing technical professionals, MESA enjoys strong support from industry. Corporations such as Boeing, Chevron, General Electric, Google, HP, IBM, Intel, AT&T, and Texas Instruments have provided funding, in-kind support, scholarships, and internships. Earning several awards of distinction, MESA was named one of the most innovative public programs by Innovations in American Government, a project of the Kennedy School of Government at Harvard University, and the Ford Foundation. MESA is also a recipient of the Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring. Expanding its services across the nation, California MESA is model for similar programs in over a dozen states.

MSP

The MESA Schools program serves mostly middle and senior high school students (some sites offer services to elementary schools) and is administered through local centers, located on university campuses, that partner with area school districts. The main program components of the MSP model include:

MESA Day Academies where students follow MESA developed curriculum that reinforce California Math and Science Standards to build hands-on projects bringing lessons learned in the classroom to reality. Students enter these projects in rigorous local competitions; winners advance to regional, and in some instances, national competitions.

MESA Periods which are classes, taught during the regular school day, dedicated to highlighting engineering, science, and mathematical theory and practice. MESA Advisors, school site teachers selected by the MESA Center, work with students in these classes to build academic attainment, peer groups, and confidence so that students graduate high school University of California eligible.

SAT/PSAT training offering additional resources and support to prepare students for these important tests.

Study Skills training offer students information about developing the most effective techniques for academic success.

Career and college exploration to bring students in contact with guest speakers from university campuses and working in industry as well as field trips to various industry sites and college campuses.

Incentive awards designed to acknowledge outstanding academic achievement and leadership.

Parent leadership, training teaching parents about advocacy skills and leadership.

Teacher training initiatives developed for school sites teachers that expand and improve learning not just for MESA students, but also across schools.

MESA students perform well when compared with non-MESA students. 81% complete Algebra by the 10th grade, allowing more time to take college preparatory classes. 61% of MESA graduates fulfilled the "A-G" requirements for University of California and California State University admission, compared with 35% of California seniors. Of MESA graduates, 57% go on to attend postsecondary institutions and major in math, science, or engineering. Of high school seniors who are African American, Latino, and American Indian, 29% are eligible for admission to a UC campus. This eligibility rate is much higher than the statewide rate of 6.2% for African American students and 6.5% for Latino students[2].

Pacific MESA Center

Established in 1993, and located within the University of the Pacific School of Engineering and Computer Science, Pacific MESA Center's MSP program serves eight hundred 4th - 12th grade students per year. Providing all of the MESA program components, Pacific MESA Center also offers students a Saturday Academy where students attend math and science workshops, from October through February, utilizing the School of Engineering's facilities. Additionally, the Center offers students an opportunity to compete in *Quiz Bowl*, a *Jeopardy* type event, focused on math, science, and engineering concepts as well as test themselves via the *Go Figure* Math Challenge in collaboration with Sandia National Laboratories. Other unique services include, Shadow Day, where high school seniors attend the university and "shadow" an enrolled student in engineering; Senior Retreat, where both students and parents are given information as well as assistance filling out college applications and financial aid forms; and the Parent Conference designed to assist parents with understanding the importance of academic attainment within math-based fields. In 2000, Phi Delta Kappa recognized Pacific MESA Center for its "Outstanding Contribution of Education." In 2007, the Center was featured by PBS as an innovative solution to improving math and science education for pre-college students in, *The Inventors: Designing the Future*, a documentary that aired nationally.

The Collaboration

In 2006, the Statewide MESA organization, located at University of California, Office of the President, collaborated with the JHU's *What is Engineering*? program to bring the class to California students. Wanting to expand learning opportunities, offer students a more realistic portrait of the demands of engineering study, and provide students with an opportunity to earn university credit at all California higher educational institutions, MESA agreed to fund the $1,700.00 tuition costs for 21 students per site. Sites were selected on competitive bases where all MESA centers across the state were invited to apply for programming. Ultimately, four sites were selected: UC Santa Barbara, CSU Fullerton, and CSU Long Beach in Southern California as well as University of the Pacific in Northern California.

Selected sties met with the Statewide MESA leadership to establish a student selection criterion that would be consistent with the *What is Engineering?* program application procedures. At a minimum, MESA students selected for participation were expected to earn a 3.2 GPA, had taken Algebra II, and have been a rising junior or senior. Additionally, because MESA Directors were familiar with their students' performance inside, and out of, the classroom, JHU agreed to admit students recommended by the Directors. While MESA students completed the JHU application packet, which included a program application, essay,

letters of recommendation, and students' transcripts, in consideration of MESA students' economic status, the application fee of $35.00 was waived. Faculty chosen by each site to teach the class were hired as lecturers by JHU. While three sties used one Faculty member to teach the class, Pacific MESA Center, in collaboration with the School of Engineering, elected to have two Faculty members teach the course. All faculty members participated in a weeklong training held at JHU prior to the beginning of class.

All MESA sites agreed to offer the course as designed by JHU during the month of July. However, while in accord with curriculum selections, MESA reserved the right to add programming components to the course. Specifically, MESA provided students with breakfast and lunch for the duration of the class; and the Southern California locations offered students transportation to, and from, their campuses. Designed to enhance class discussion and lab experiences, MESA also included three field trips to industry sites during the four-week period. At the end of the course, MESA elected to stage a closing luncheon showcasing breaking each student teams' spaghetti bridge. Participants, parents, campus officials, legislative representatives, and MESA program stakeholders were invited to attend the event. In 2007, the *What is Engineering?* program institutionalized the industry site field trips and closing event.

Course Content and Objectives

Course Objectives

The objective for this class is straightforward: to deliver an academic curriculum that broadens the STEM interests and expectations for pre-college students. This is accomplished through hands-on, innovative laboratory experiences and projects, which complement the lecture material. In doing so, students are challenged to think differently while increasing their ability and confidence in solving new problems.

Course Content

Generally speaking, course content is structured such that students gain exposure to the four core branches of engineering; namely, topics related to civil, mechanical, electrical, and chemical engineering are covered. While this material comprises the backbone of the course, it should be stressed that the interdisciplinary nature of engineering, especially in today's society, is emphasized throughout. Moreover, flexibility exists in the course schedule to spend time on more interdisciplinary and "newer" branches and technologies, such as bioengineering, nanotechnology, alternative energy, etc.; this coverage varies from site-to-site and is primarily at the discretion of the individual instructors.

As a means of describing the course coverage, the assignments that contribute to the course grades for the students will be discussed. The assignments can be divided into four general categories; those involving *(1)* a laboratory activity, *(2)* communication skills (written and/or oral), *(3)* a spaghetti bridge project, and *(4)* the final exam.

The four laboratory activities and descriptions are as follows:

(a) Materials Testing Lab – using spaghetti of different thicknesses, exercises involving bending, buckling, and tension are performed. The tensile testing apparatus is

shown in Fig. 1. Concepts such as stress, strain and Young's Modulus are introduced.

(b) Remote Measurements Lab – armed with only a meter stick, some tape and a length of string, students are required to estimate large distances, such as the straight-line distance between the tops of two buildings. The importance of estimation and the propagation of error are concepts that are stressed during this activity.

(c) Chemical Processes Lab – activities related to chemical separation techniques, namely distillation and chromatography are performed.

(d) Circuits/Robotics Lab – a "virtual" lab available through JHU's website (http://www.jhu.edu/virtlab/logic-circuits/) is used to reinforce the operation of digital logic with emphasis on NAND gates. In addition to several exercises, the virtual lab is used by students to design a circuit that allows a robot to follow a light source, and the students follow up this virtual activity by physically wiring a circuit that is then tested on a robot (Fig. 2).

The components that fall under the "communication" category include the following:

(a) Mousetrap Design – the design of a mousetrap while limited to certain construction materials and the communication of that design through a list of construction directions.

(b) Research Essay – a written essay on a topic of interest related to engineering, such as nanomachines, robotics, composite materials, etc.

(c) Oral Presentations – oral presentations on an engineering topic of interest.

(d) Book Essay – a written essay on either Thomas Friedman's *The World is Flat: A Brief History of the Twenty-First Century* or Eugene Ferguson's *Engineering and the Mind's Eye*.

The third component of the course grade is a spaghetti bridge project; this is the most time-intensive portion of the course where the design and construction of the bridges spans roughly three of the four weeks of the course. Students use another virtual lab available through JHU's website (http://www.jhu.edu/virtlab/bridge-designer/) to first design a bridge which spans a certain distance before using spaghetti and epoxy to construct their design. At the end of the course, a competition is held where the bridges are loaded until failure (Fig. 3).

The take home final examination, developed and graded by JHU, is administered at all sites. In order to receive JHU credit, students must earn and "A" or "B" on both the final exam and the course deliverables that are discussed above. Students who do not earn JHU credit, but complete the class, receive a certificate of completion from the *What is Engineering?* program.

Methods for Assessment

Surveys were administered at each site before the class began and upon completion of the course. The results of these surveys are discussed in detail in a section later in this paper.

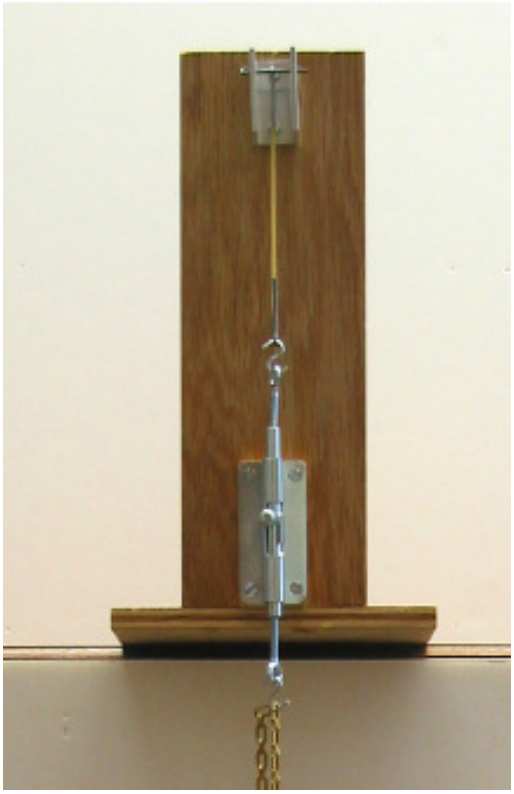

Figure 1: Tensile testing apparatus for the materials testing lab.

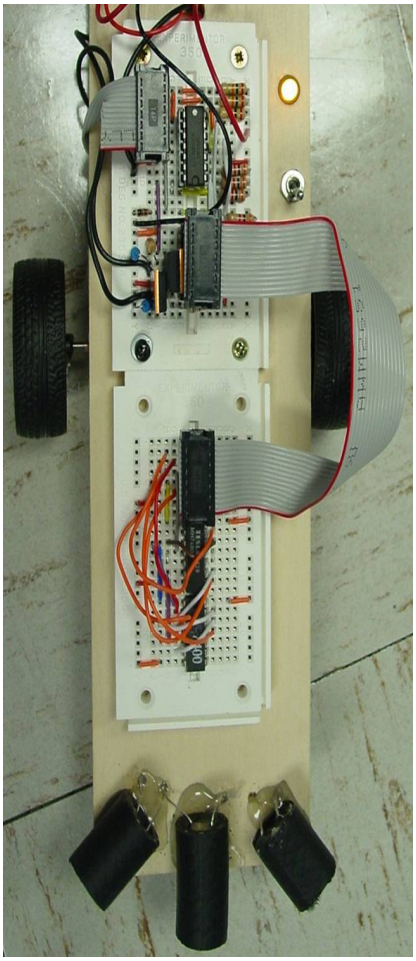

Figure 2: Robotic vehicle used to test the digital circuits designed and wired by the students.

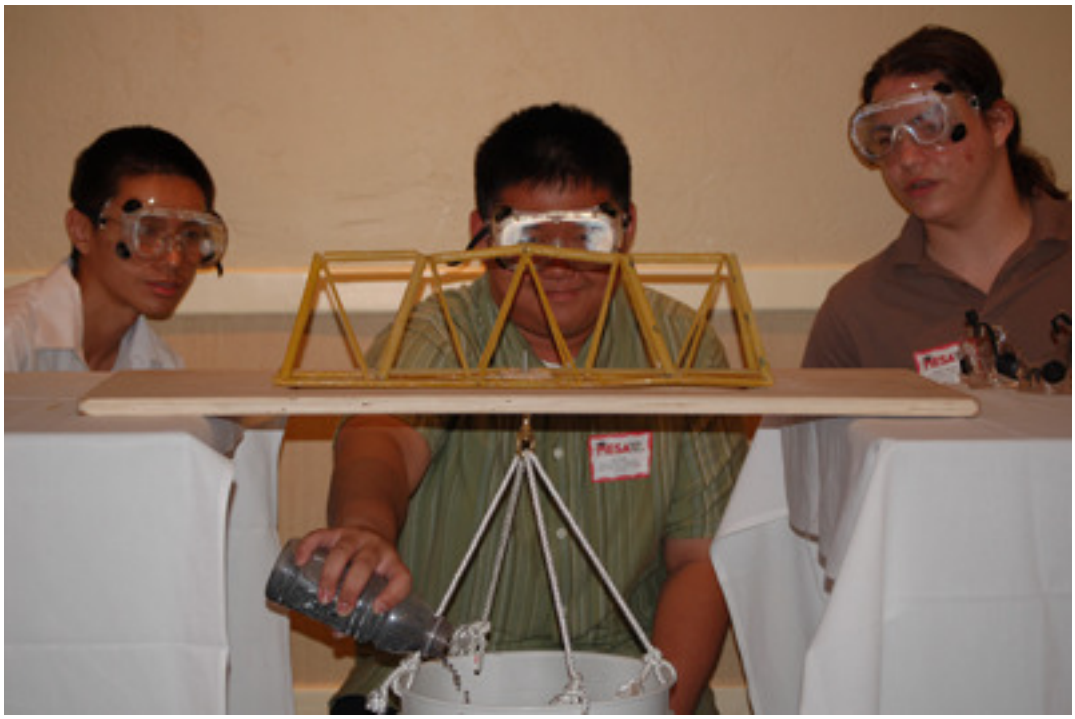

Figure 3: Spaghetti bridge testing.

Results and Discussion

A twenty-two question survey was conducted at eight sites (N = 189 students total responded) prior to the course offering in summer of 2007. Note that this survey was not available the summer of 2006. Another survey was conducted after the course was conducted with 63 respondents following summer 2006 and 104 respondents following summer 2007. The following percentages for summer 2006 and summer 2007, respectively reflect a response of "strongly agree or agree" for all of the aforementioned surveys.

Course preparation

Only 24% and 39% of students for summer 2006 and summer 2007, respectively agreed that they were "well-prepared to take this course." Despite the acceptance criteria (desired top 25% of their class) to suggest that they were prepared, even the perception that they were not prepared to take this course could adversely affect their enthusiasm for engineering post course. The University of the Pacific students had a range of chemistry and physics backgrounds such that some students had both chemistry and physics while others had either chemistry or physics. The lecture background material along with the team approach throughout the course was an attempt to alleviate any preparation concerns.

Course content

47% and 43% of students, for summer 2006 and summer 2007, respectively agreed that "this course covered too much content." The course is extremely aggressive in both the amount of content covered, and the time in which to cover this content. For example, statics (specifically trusses) is a major component of the course culminating in the spaghetti bridge design competition. To put this *What is Engineering?* course component in perspective, it would not be until mid-semester until trusses are covered in the University of the Pacific's sophomore level engineering mechanics (statics) course. Is it possible that the amount, breadth, and timing of such content could adversely affect their enthusiasm for engineering? 65% and 85% agreed that they "needed more time to cover topics presented in class." 47% and 55% agreed that "this course was overwhelming." Finally, 82% and 90% agreed that "this course was challenging" with 51% and 47% agreeing that they "would take this course again [knowing what the course entails]."

Teamwork

Teamwork is a major theme throughout the course. 69% and 71% agreed that they "liked working in teams" with 55% and 72% agreeing that "team members contributed equally to assignments" for summer 2006 and summer 2007, respectively.

Success defined?

Prior to the course in summer 2007, 61% of students responded favorably that they plan to take the course "because [they] want to be an engineer." However, when asked "as a result of this course, I plan to become an engineer" this number dropped to 44% post course for summer 2007 (which is up from 34% in summer 2006). This drop in engineering interest post course is certainly open to interpretation, but it does beg the question: how is success defined?

One argument is that this decline in engineering interest reflects an engineering enlightenment, i.e. these students would likely drop engineering eventually. Assuming this is the case, this course then serves as an efficient way of identifying their likes and dislikes. In point of fact, 78% and 87% agreed that "the topics presented in this course helped me understand the field of engineering." This suggests that "understanding the field of engineering" may not necessarily yield an increase in engineering enrollment.

In contrast to this efficiency argument, perhaps success should be measured as maintaining or exceeding that initial survey input benchmark of 61% that "want to be an engineer" in summer 2007. Akin to any wine tasting experience, it may be hazardous to judge a winery based on one visit, or worse, one particular variety of wine in any given year. Although it is important to cover as many engineering topics as possible, an optimization of both breadth and depth needs to be considered throughout any introductory engineering course in order to have a positive introductory engineering learning experience.

The Future of *What is Engineering?*

What is Engineering? has proven to be a challenging, mind-expanding course for college-bound high-school students interested in STEM. Like any course following the continuous improvement model, it is a work in progress with input coming from at least eight different

sites as of this writing. With only two years at the University of the Pacific, it is incumbent to continue such surveys and track the "alumni" of this course to make sure that we are making the proper changes that ultimately increase the number of students interested in STEM.

Bibliography

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