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A Project Based Approach To Introduction To Engineering

Dr. Rouzbeh Tehrani, Temple University

Rouzbeh Tehrani is the graduate coordinator of the civil and environmental engineering department and an assistant professor at Temple University. He also serves as the co-chair of AEESP education committee. He has been involved in teaching and developing labs and teaching materials for several courses such as Introduction to Engineering, science GenEds, Environmental Chemistry and Microbiology, and Water Quality and Treatment since 2013.

Dr. Mohammad F. Kiani, Temple University
Dr. Evangelia Bellas , Temple University
Dr. John Joseph Helferty, Temple University

Dr . John J. Helferty is an Associate Professor of the Department of Electrical and Computer Engineering. He received his undergraduate degree in Electrical Engineering Technology from Temple University in 1983, his M.S. and Ph.D. in Electrical Engineering from Drexel University in 1984 and 1987, respectively. Dr Helferty has received four American Society for Engineering Education Faculty Fellowships, of which two were at the Naval Air Development Center in PA and the other two were at NASA's Jet Propulsion Laboratory in Pasadena CA. Currently he is working on NASA funded projects for the design and construction of autonomous mobile robots and rotorcraft that perform coordinated tasks. Other NASA projects include high altitude ballooning experiments and payload design for sounding rockets flown out of Wallops Island Flight Facility.

Prof. Won H Suh, Bioengineering Department, College of Engineering, Temple University

Dr. Won H. (Jon) Suh is an assistant professor in the Bioengineering Department at Temple University, Philadelphia, PA. Prior to joining Temple as a faculty member, Dr. Suh was an assistant project scientist and postdoctoral fellow at the University of California, Berkeley (2009-2012) in the Department of Bioengineering. He was an Otis Williams Postdoctoral Fellow in Bioengineering at the University of California, Santa Barbara (2008-2010), which is where he started working in the area of stem cell engineering, biomaterials research, bionanotechnology, nanomedicine, and nanotoxicology. He received his Ph.D. from the University of Illinois at Urbana-Champaign (2006) and received his M.S. (2002) and B.S. (1998) degrees from Seoul National University. His current research focuses on developing enabling technologies (e.g., biomaterials, nanomaterials, biomolecules) for adult stem cell research.

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Rouzbeh Tehrani, John J. Helferty, Mohammad F. Kiani, Won H. Suh, and Evangelia Bellas
Temple University, Philadelphia
r.tehrani@temple.edu, helferty@temple.edu, mkiani@temple.edu, whs@temple.edu, evangelia.bellas@temple.edu

***Abstract* - A new model has been designed and implemented for the Introduction to Engineering course at Temple University. In the past, the course was run as a large lecture style and various topics were covered, such as time management, career options, on-campus tutoring and resource centers to name a few. Based on student feedback and low retention rates, it was obvious that a new model was needed. The focus was to be much more hands-on and use a project-oriented approach. In addition, multiple instructors were employed from four departments, and it was decided that each instructor would teach topics very specific to the departments. The large lecture mode was removed in favor of splitting the freshman class of approximately 320 students in two sections of 160 each. Then, within each section, students are divided into four groups of approximately 40 students per group. Students do rotations among instructors from the various departments. The entire course is centered on the design projects specific to that departments/instructors' field of expertise. The course begins with a week of introduction to the course, requirements and grading, rotations, and scientific methods. Each rotation takes two weeks to complete. During these rotations, students are taught to use 3D printers, Arduino microcontrollers, MS Excel, LED circuits, laser cutters, microscopy, SOLIDWORKS, UAVs, K'NEX, and water quality measuring devices. The last part of this course is completion of a 4-week interdisciplinary design project. Students are allowed to select any of these projects regardless of their discipline. The interdisciplinary projects offered are bioengineering and electrical engineering, civil and environmental engineering, civil and mechanical engineering, and mechanical and electrical engineering. We are currently monitoring retention rate, student success in match extensive courses, and students' education experience.**

Index Terms – First Year Engineering Education, Hands-on Experience, Multidisciplinary, Project-based

INTRODUCTION

Many engineering programs are facing the problem of low retention rate as they are losing students to other colleges or institutions. Thus, teaching an introductory course to freshman students has become a challenging task for those who are interested in increasing freshman retention rate and improving students' experience with engineering education. Traditionally, such introductory courses were considered as personal courses where faculty designed teaching materials from scratch, possibly to fulfill their own teaching or research objectives [1]. But current literature suggests that faculty are moving away from the earlier models in an attempt to increase retention rate by redefining first year engineering education [1,2,3]. Recently, there has been an emphasis on engineering design and hands-on, team work based projects. Such practices have shown to be successful in increasing retention rate and improving learning experience [3].

At Temple University, Introduction to Engineering is a freshman multidisciplinary engineering course offered to all undergraduate students. Previously, this course was run as a large lecture covering various topics such as time management, career options, on-campus tutoring and resource centers to name a few. In a study conducted during the 2009-2010 academic year, the authors studied student intra-university freshmen transfer out of the College of Engineering to non-STEM disciplines. A snapshot of the transfer statistics is presented in Figure 1. With an average annual enrollment of 250 in the freshman class, the number of transfers to non-STEM disciplines represents a 33% transfer rate.

Between 2012-2014 our college sought to increase retention by improving student learning experience in freshmen engineering design, which has increasingly become a gateway course for freshmen exploring a career in engineering. Teaching this course as a purely lecture intensive course has not yielded satisfying student experience or retention rate. The authors sought to incorporate some new methods explored by researchers in the field of engineering education and explored possibilities like studio based learning [4,5], participatory design [6, 7], case studies [8] and reverse engineering [9]. To incorporate some of these ideas in freshmen design was a challenge, given the lack of mathematical foundation necessary to understand basic design concepts.

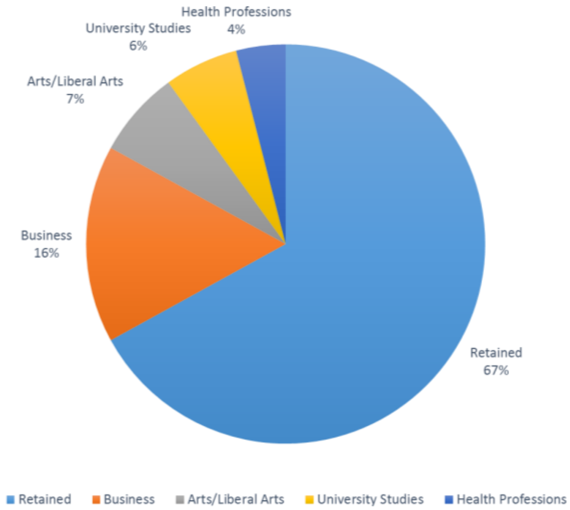

FIGURE 1
INTRA UNIVERSITY TRANSFER FOR 2009-2010.

In addition to introducing students to the process of engineering design early in the curriculum, the course was also designed to help two specific groups of students:

- Students with undeclared major: A course in design is typically the culmination of an engineering curriculum. However, by presenting the fundamental concepts at freshman level, this course is designed to give such students a good understanding of the major.
- Engineering majors with undeclared discipline: The curriculum includes modules from several engineering disciplines, providing a preview of each major.

The course used a design based, cross-disciplinary syllabus with emphasis on team based design. The course utilized digital and analog circuit design; computer aided modeling and rapid prototyping tools to introduce students to the process of engineering design. Using this knowledge, the students designed and built a prototype of multiple cross-discipline design projects representative of each of the disciplines within the college.

In 2016, based on student feedback and concerns over low retention rates, it was decided to have an emphasis on introducing students to real world and contemporary engineering problems with hands-on experience and employing a multidisciplinary project-based approach. Since 2014, the course has gone through iterations and corrective actions have taken place. The objective of this newly reformatted course is to motivate students to pursue engineering programs, with a focus on learning and practicing scientific methods, critical thinking, problem-solving, design creativity, ethics, team work and soft skills. Similar approaches have been practiced by other engineering schools as well [2,3].

The latest format of the course is organized into six different sections: introduction (one week long), four departmental rotations (two weeks long each for a total of eight weeks), and a final design project (four weeks long). After an introductory interactive presentation on the scientific method and engineering design, the students are divided into four smaller groups of approximately 40 each as they go through departmental rotations. During the last four weeks of the semester, students choose one of four interdisciplinary projects during which they form a team to design, build, test, and present a final project. In the following sections, we review each departmental module and the final project associated with that module.

In order to avoid redundancy and expose students to different teaching styles, each rotation has a unique format and content. For example, professional development is covered in civil and environmental module, and ethics and plagiarism are covered in bioengineering module. While it is needed to provide fundamental information and basic tools to students, we were cautious in drafting the content to avoid overwhelming students with many topics and redundancy.

SCIENTIFIC METHOD AND ENGINEERING DESIGN

The first module in this course was organized, in part, based on our extensive experience with developing and teaching a very successful Gen-Ed course ("The Bionic Human") that introduced non-engineering students to the applications of engineering technologies in healthcare [10]. Our experience in this Gen-Ed course indicated that focusing on fundamentals of science and engineering (the scientific method, basic number systems, basic understanding of electromagnetism, etc.) is far more instructive and useful to beginners than teaching specific equations or having them crunch numbers, for example. Given that students expressed a strong interest in improving and expanding the first part of the Introduction to Engineering course, which provided an overview of engineering design and issues that impact the practice of engineering, we developed a one-week module reviewing the basic concepts in the scientific method and engineering design. During this module, students are introduced to how evidence is collected and evaluated to form scientific theories and how available information can be evaluated and analyzed to assess their scientific validity. This presentation was then extended to discuss how engineering design leverages the scientific method to develop a rational methodology for developing and selecting designs to solve everyday engineering problems. A quiz at the end of this module that is based on a number of case studies in the scientific method and engineering design evaluates the knowledge of the students in these areas.

BIOENGINEERING MODULE AND FINAL PROJECT

The Bioengineering (BioE) modules were initially designed to present the field to future bioengineers. This includes the interdisciplinary nature of BioE and the various subdivisions, including medical devices, biomechanics, biomaterials, neuroengineering, bioimaging, tissue engineering and regenerative medicine, cell and molecular engineering. The concept of tissue engineering was highlighted as it encompassed several areas including 3D rapid prototyping, biomaterials, biomechanics, and microscopy/imaging. The lab was designed to incorporate the aforementioned areas by creating a brain-like tissue model.

Hands-on labs were designed where students assembled a 3D Printed Chip to serve as a mold for tissue-like constructs consisting of cells encapsulated within polymeric hydrogels, much like organ-on-chip technology. The differences between quantitative and qualitative results were discussed while the concept of hypothesis testing was introduced. Here, students compared the measured chip dimensions to the original SOLIDWORKS design to introduce the concepts of precision, accuracy and engineering tolerance. The chips were designed to allow for easy in-lab fabrication, i.e. a silicon adhesive was used to adhere a glass coverslip to the 3D Printed Chip. To introduce biomaterials, a two component polymer system (alginate and calcium chloride) was used. The components were dyed yellow and blue, thus when mixed within the 3D Printed Chip would form a green polymer gel. This demonstrated the principals of polymer cross-linking, specifically ionic cross-linking. Students were asked to track polymerization, by monitoring color change and material stiffness by probing the gelled material with a pipet tip. Finally, the students encapsulated cells within the polymer. Here, students were introduced to light and fluorescence microscopy techniques to visualize the cells within the 3D Printed Chip polymer construct. During the rotation, mini- lectures on wet lab safety, lab protocols, plagiarism, citing sources and writing a laboratory report were presented.

The Final Project is presented as a series of design challenges, where students were expected to undergo the engineering process of designing, building, testing and reiterating their designs. Currently, the BioE Final Project is coupled with circuit design and electrical engineering components to promote interdisciplinary learning. Students engineered an LED circuit with customized polymer housings (via iterative 3D Printing) for photo-polymerization of select polymers. Students were tasked to make the polymer within a suitable material stiffness range for brain tissue. Once they learned to control polymer properties by photo-polymerization, they would perform mechanical testing before finally encapsulating brain cells.

As part of continuous improvement and based on student feedback, chemistry and biology concepts were substantially reduced. We introduced quantitative decision making through introduction of statistical analysis methods (i.e. means, standard deviation, t-tests) in MATLAB. This built on the principles of engineering design and iterative design by explaining algorithm-based decision making processes to inform the tissue engineering project. In future BioE modules, students will continue to develop a simplified "brain-on-chip" organ model. This requires students to explore engineering design, iteration, 3D printing, statistical decision making, polymerization, (bio)material properties, microscopy and cell and tissue engineering. We will continue to use MATLAB as an important enabling tool but the labs will be revised to include more connections between design input (i.e., SOLIDWORKS of 3D printed design) and output (i.e., 3D Printed Chip). Custom-designed LED circuits to photo-polymerize polymers with varying material properties will continue as BioE's Final Project but adjustments will be made so the electrical engineering components are well-explored and tissue engineering applications fully explained. Finally, given that the BioE module is team-based and the Final Project culminates in a final oral presentation, we will introduce a lecture on the dynamics of team work, including conflict resolution, managing expectations and professionalism, and communication/presentation skills.

CIVIL AND ENVIRONMENTAL ENGINEERING MODULE AND FINAL PROJECT

The purpose of this module is to introduce students to civil and environmental engineering curriculum and profession. On the first day of this module, the importance of engineers' role in society is deliberated with real world examples and with an emphasis on the necessity of practicing as a registered Professional Engineer. Students learn about sub-disciplines of civil and environmental engineering and areas of overlap. Large engineering firms and relevant governmental agencies are introduced, and a few job descriptions of newly advertised employment opportunities are shown in class. Later, future employment projections from the US Bureau of Labor Statistics and expected salaries are discussed. And finally, the first class ends with a review of ASCE report on current national status of America's infrastructure. Students are highly recommended to have a follow up reading on the issues discussed.

Once students are introduced to civil and environmental engineering, the class continues with a sequence of lectures and following labs for the next two weeks. This is to make sure that students are introduced to the fundamentals and concepts of engineering while having a hands-on experience. As for introducing civil engineering, the topics of units of measurement, density, stress, strain, tensile and compressive strength are discussed. Students have this opportunity to make concrete samples based on their own calculations and to test their samples on the last day of this module. Various iron and aluminum alloy samples are also tested so students can have a better understanding of a stress-strain diagram, elasticity and plasticity. Students are asked to calculate modulus of elasticity for various materials using the data collected from labs and by using MS-Excel. In assignments, real word examples are given to make sure students have a better understanding of force, pressure, and relevant units.

As for the introduction to environmental engineering, students are familiarized with treatment processes involved in treating Philadelphia's drinking water. The focus is on coagulation and flocculation (C&F) process. Students learn about turbidity, suspended particles, dilution equation, chemical and physical principles of C&F. Once they have conducted the experiment, they are asked to plot the data using MS-Excel to first find a function for their observation and second to find a minimum for the function obtained.

This Final Project has gone through three changes in order to provide better education and training for students.

The first Final Project was designing and building a truss bridge using popsicle sticks, and students were also introduced to Bridge Designer 2016 software (free educational software). Based on students' performance and feedback, it was observed that most students were capable of learning more and showed interest in learning an advanced software. Thus, the SOLIDWORKS was introduced to students during the ME module with a focus on design and simulation of a truss bridge. As for students in environmental engineering, based on their feedback and surveys an environmental project was added. Therefore, students had an option of choosing either a bridge design for civil engineers or a coagulation & flocculation project for environmental engineers. As a part of our efforts for continuous improvement and having a multidisciplinary approach, later the bridge design project combined mechanical and civil engineering students for one project and with an emphasis on manufacturing and simulation (for more details please read the civil and mechanical engineering Final Project section). As for students who were interested in civil and environmental engineering, a new project was developed. The new project requires students to design and build a prototype water treatment setup to improve surface water quality for a disadvantaged community. Students were given a few lectures on water quality and surface water treatment. Basics of sedimentation, filtration, C&F, and hydrology were introduced to students. Students were asked to build the main structure of the prototype out of concrete. Concrete mixing and design was once more reviewed for students. Finally, students were asked to present their work. MS-Excel is the sole software used in this module. Students learn how to enter data, plot diagram, and perform linear and polynomial regressions. Errors and calculation of coefficient of determination is briefly discussed. The main focus is on learning how to observe a phenomenon, collect data, and try to find a trend. As for the application of mathematics in engineering, students are asked to find the minimum of a second order polynomial function for an environmental engineering example.

ELECTRICAL AND COMPUTER ENGINEERING MODULE AND FINAL PROJECT

The ECE component mainly focuses on employing the Arduino microcontroller board in a variety of experiments and the design component is that of constructing a quad-rotor flying drone. The Arduino was chosen for its easy to use Integrated Development Environment (IDE), inexpensive, large community of construction, programming, electronics projects [11, 12]. The very first day of class a poll is taken as to how many students have actually programmed in a language such as: C, C++, Java, Virtual Basic, HTML, etc. Typical responses indicate that less than 5% of 240 students have had no programming experience. Rather than devote the ECE section of the course to just programming we decided to provide "bare-bones shell programs" found on the Internet and in the examples section of the Arduino IDE. Since the students lack both basic programming and bread-boarding skills emphasis was placed upon the basic concepts of what an embedded microcontroller system is comprised of and how it interacts with real world hardware. It should be noted that the students were given example code at the outset of each activity and the real challenge comes at the end of each activity where the students are then challenged to take what they have learned and extend the example code they were given. For example, take the ultrasonic activity. In this activity the students use Parallax ultrasonic sensors to measure distances to an object using basic code from the Arduino examples. The extended part of the activity is as follows: Connect a servo motor to an analog (PWM) port and an LED into an I/O port. Place an object in front of the sensor. If object is over 30cm away from the sensor then leave the LED and motor off. If the object is between 30 cm and 5 cm then make the blinking/timing rate of the LED as a function of the distance the object is away from the sensor. If the hand is within 5 cm then turn on both the LED and the motor. While straightforward for a majority of inexperienced programmers this is a challenge in using IF-ELSE constructs. It also requires them to incorporate multiple, external hardware modules into a single C-code program. In all of the projects the students learn how to setup I/O ports in both input and output modes, use pulse width modulation to control both DC and servo motors, use analog to digital converters to read sensors such as photo-resistors thermocouples.

The Final Project, jointly ECE/ME, is to design a quad-rotor drone for indoor flight. In this project, freshmen engineering students "will get to think like 7 year olds again" and design, construct and fly quad-rotor drones made from the childhood favorite construction materials-K'NEX parts. Use of the K'NEX parts allow for not only easy design and construction but also modifying the design "on the fly". First, all of the structure is from K'NEX parts except for a 3D preprinted motor mount. All other structural parts of the quad-rotor are completely comprised of K'NEX parts. This allows for the easy modification of design from large booms for stable "slow" motions to short booms for "fast" highly maneuverable (unstable) flight modes and placement of the battery and motors also requires one to understand the concept of center of gravity. The easy construction and design modification also allows for quick reassembly if a crash occurs the drone. The other components for the quad-rotor are: one Q-Brain 4 x 25A Brushless Quadcopter ESC, one OpenPilot CC3D Flight Controller, four EMAX Grand Turbo motors, one Graphene 14.8V LiPo battery, one Spektrum DXE Transmitter, one Spektrum AR610 Receiver and four Propellers. It should be noted that the size of the propellers and the rating of the motors are fixed. In the future different propeller sizes and motor rating will be introduced to further experiment in different performance characteristics. As a final competition the quad-rotor craft navigate an indoor 3D maze made from hoola-hoops to demonstrate their K'NEX quads capability.

MECHANICAL ENGINEERING MODULE AND FINAL PROJECT

In previous years, the emphasis in the mechanical engineering (ME) module was to train students on the basic functions of SOLIDWORKS and then organize them into teams at the end of the class to build a project primarily based on a recipe. The students were encouraged to use their knowledge of SOLIDWORKS in their projects but there was no organic connection between the two components of the course. Our experience with this approach indicated that these concepts were not being internalized by the students and they could not show mastery of these skills at the end of the semester. Therefore, two fundamental changes were introduced into the Introduction to Engineering course. First, the focus of the ME module was shifted from simply teaching computer skills to ensuring that the students have a basic understanding of the central role of modeling in modern engineering practice. The students were introduced to basic concepts of how physical phenomena can be modeled using conceptual or mathematical approaches with a focus on the use of computational approaches to model physical entities, design engineering structures and simulate various conditions that these structures may experience. An introductory discussion of the challenges associated with translating design concepts from computational models to physical structures was also presented.

Second, the Final Project (design of a truss bridge) was dovetailed to the ME module with a focus on modeling and design before building a structure. The project consisted of using their modeling skills to select between different designs, simulate various conditions, and then decide on the best design before building their structure. The students also used their final SOLIDWORKS design to fabricate their own parts using a laser cutter. As a major component of the final presentation of the project, each team was responsible for comparing their predictions from their modeling studies (e.g. displacement of various members in the bridge) to actual measurements made in the lab and for explaining any discrepancies. To further increase the interdisciplinary character of the Final Project, starting in Spring 2017 the mechanical engineering and civil & environmental engineering (CEE) projects were combined into a cooperative project to design and build an underpass truss bridge (led by the ME team) to support a water treatment facility (led by the CEE team). The two teams then collaborate to design and simulate their overall system in SOLIDWORKS, fabricate their parts using laser cutters and other techniques, build and test the final system, and present their work.

Several ME faculty initially had reservations regarding the level of complexity and work that was being introduced into this course as outlined above. However, evaluation of the homework assignments from the ME module and the Final Projects indicates that the students were able to internalize the introductory concepts presented in class and use them effectively to design, simulate, and build relatively sophisticated structures. Of particular note was that almost every team used SOLIDWORKS simulations to rationally select between different designs, was able to justify their final design choice based on the results of their computational model and reasonably explained discrepancies between their computational predictions and experimental observations. A large majority of the students had very positive evaluation of their experience in the ME section of the course as evidenced by comments such as “This module was taught very well and sparked an interest for me in mechanical engineering.”

CONCLUSION

Based on current literature, course assessment and our experience, many new features have been incorporated into our freshman Introduction to Engineering course. Final projects are interdisciplinary and teaching materials are multidisciplinary in an attempt to cover engineering design, the scientific method, professional development, software skills, ethics, writing, soft skills and team work. Based on our student feedback, most students believe that the course content has been very valuable to them and they particularly enjoy competing in final projects. We are in the process of systematically evaluating if these students are successful in pursuing engineering programs and passing math extensive courses.

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AUTHOR INFORMATION

Rouzbeh Tehrani, Assistant Professor and Graduate Coordinator, Department of Civil and Environmental Engineering, Temple University, r.tehrani@temple.edu

John J. Helferty, Associate Professor, Department of Electrical and Computer Engineering, Temple University, helferty@temple.edu

Mohammad F. Kiani, Professor, Department of Mechanical Engineering, Temple University, mkiani@temple.edu

Won H. Suh, Assistant Professor, Department of Bioengineering, Temple University, whs@temple.edu

Evangelia Bellas, Assistant Professor, Department of Bioengineering, Temple University, evangelia.bellas@temple.edu