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Work in Progress: Inclusion of an Engineering Design Experience in Freshman Introductory Engineering Courses at a Hispanic-serving Institution

Dr. Matthew Lucian Alexander P.E., Texas A&M University - Kingsville

Dr. Alexander graduated with a BS in Engineering Science from Trinity University, a MS in Chemical Engineering from Georgia Tech, and a PhD in Chemical Engineering from Purdue University. He worked for 25 years in environmental engineering consulting before joining the faculty at Texas A&M University-Kingsville in 2015.

Mr. Rajashekar Reddy Mogiligidda, Texas A&M University - Kingsville

I am working as a Lecturer in the department of Mechanical and Industrial Engineering at Texas A&M University-Kingsville since 2016. I graduated from Texas A&M University-Kingsville with a Master's in Mechanical Engineering in 2016. I am currently pursing PhD in Engineering as a part time student while working as a lecturer.

Dr. David Hicks, Texas A&M University - Kingsville

David Hicks is an Associate Professor in the Electrical Engineering and Computer Science Department at Texas A&M University-Kingsville. Before joining TAMU-K he served as Associate Professor and Department Head at Aalborg University in Esbjerg, Denmark. He has also held positions in research labs in the U.S. as well as Europe, and spent time as a researcher in the software industry. His research interests include knowledge management, software engineering, mobile computing platforms, and computer science education. Dr. Hicks received his B.S. degree in computer science from Angelo State University, and his MCS and Ph.D. degrees in computer science from Texas A&M University.

Work-in-Progress: Inclusion of an Engineering Design Experience in First-year Introductory Engineering Courses at a Hispanic-serving Institution

Introduction

The first-year introductory engineering courses taught by three departments in the Frank H. Dotterweich College of Engineering at Texas A&M University-Kingsville have incorporated engineering design instruction and hands-on design projects in the last two years as part of NSF grant award #1928611. A primary objective of this grant is to increase the retention and persistence of minorities in the engineering programs by incorporating high-impact enrichment activities into courses early in the student's academic career. A logical course to include high-impact activities for first-year students is the introduction to engineering courses in the departments, which are titled "Engineering as a Career" (GEEN 1201), within the Frank H. Dotterweich College of Engineering.

This work presents the approach used for a hands-on design project implemented by instructors in three such courses, as supported by the NSF grant, in fall 2019 and fall 2020 offerings. The three courses were separate sections for chemical and natural gas engineering, mechanical engineering, and electrical engineering and computer science. The GEEN 1201 courses have been offered in the Frank H. Dotterweich College of Engineering since fall of 2018. Prior to that, all incoming freshmen were required to take a university-wide student success course in place of the GEEN 1201 course. These design project experiences were included only in the 2019 and 2020 offerings of the chemical engineering and mechanical engineering sections, while design projects were included in all three years of the electrical engineering / computer science section.

The design experience included in these GEEN 1201 courses was intended to inspire interest students in all ethnic groups. It should be noted that the majority of undergraduate students at our university are Hispanic, and the percent of Hispanic students in the 2018, 2019, and 2020 cohorts of the GEEN 1201 course are given in Table 1. The percentages ranged from 55% to 82%, and average 72%. Also, the percentage of females registered in these courses ranged from 6% (mechanical discipline) to 24% (chemical discipline) for the 2019 cohort of GEEN 1201. Hispanics face challenges in selecting and remaining in STEM majors due to (a) potential social stigma against studying STEM, including engineering, and (b) not having sufficient STEM role models [1].

Table 1. Percentage of Hispanic students in the Engineering as a Career Course

Semester	Percent of Hispanics in Course		
	Chemical and Natural Gas	Electrical and Computer Science	Mechanical
Fall 2018	65% (17)‡	81% (21)	70% (23)
Fall 2019	82% (17)	80% (15)	65% (17)
Fall2020	69% (13)	55% (22)	82% (11)

‡ -- number of students in course is provided in parentheses, upon which statistic is based
Source: [2]

The engineering design process is central to the engineering profession, and is considered the pinnacle of professional engineering practice. Across the US, undergraduate engineering programs incorporate engineering design instruction as a curriculum capstone activity in the senior year of the program. However, design experiences are not uniformly incorporated into courses prior to the capstone experience. In the chemical engineering department at Texas A&M University-Kingsville, short or mini-design experiences have not been historically included in the curriculum prior to the capstone design experience for the seniors. Exposure to the engineering design process in lower level courses can better prepare the students for the capstone experience, as well as motivate them to continue their studies when they may face academic challenges part way through their undergraduate career [3], [4]. Experiential approaches have been shown to result in greater empowerment and ownership for students pursuing STEM academic careers [5], [6], [7], [8]. For these reasons, engineering design problems were selected for implementation in the three GEEN 1201 courses, so as to positively impact the retention of Hispanic engineering students per the NSF grant objective.

Implementation of Design in the First-Year Course

The students in the first year of the chemical and natural gas engineering section of GEEN 1201 (fall 2019) conducted a hands-on design project involving the development of a simple, low-energy demand water purification system that would generate clean non-potable water from silty water held in a stock pond, such as on a farm or ranch. Each team was challenged to develop a prototype treatment device that would treat the water at a rate of 100 to 300 milliliters per minute for a minimum period of 10 to 15 minutes, under gravity flow conditions. The instructor provided the problem definition directly to the students, rather than allowing the students to develop a problem statement from a more general needs assessment, because of the limited duration of the design project. The instructor divided the students into groups of three to four persons for this design experience. Each student team was provided with a variety of low-cost water treatment materials, which they used to test several different treatment approaches, such as filter paper, sand, or carbon filtration for treatment efficacy. Two-inch PVC piping materials were provided for the students to serve as their treatment apparatus. Figure 1 presents pictures of the silty water used as the treatment challenge, and student-created treatment devices.

Figure 1. Water (silted) and student treatment devices for GEEN 1201 (Fall 2019).

The treatment testing was conducted in the chemical engineering unit operations laboratory, and was the first time the freshmen students had been in this facility. The treatment testing performed by the students provided hands-on experience in basic fluids concepts. The students assessed their treatment efficacy qualitatively by visual clarity of the silty water. In the second year cohort (fall 2020), a similar water treatment problem was posed to the students, involving one of two dissolved organic contaminants isopropanol or ethylene glycol dissolved at levels of 2 to 5 weight percent in the water. The same treatment flow rate and time period were utilized as in the fall 2019 project, although a peristaltic pump was provided to the students to ensure a sustainable flowrate through student-selected media. The same treatment materials were used with this cohort, however the students assessed treatment efficacy by measuring residual organic content using refractive index readings. Some of the student teams experienced different outcomes than they expected in their testing, which demonstrated to them the importance of process testing in technology evaluation, and the need for the prototype-test-repeat cycle of engineering design. At the end of the semester, each student team prepared a written design experience report and presented its findings in a group presentation.

The students in the chemical and natural gas engineering section of the GEEN 1201 indicated that they enjoyed working through the design challenge, and that the hands-on testing of various process ideas was seminally helpful in understanding the variabilities inherent in performance testing based on chemical properties. The students also displayed a high level of teamwork, as less than 10% of the students demonstrated issues or problems with contributing to the share of work confronting each team.   Based on student comments provided in the student course rating of the instructor, the laboratory work was a highlight of the course.

The introductory course taught to electrical engineering and computer science students in the fall 2019 semester included a robot building team project and competition designed to further engage students with the course content. Teams consisting of three to four students were formed at the start of the project. Each team was given the task to assemble a small robot and write software for the same such that it is capable of following a path designated by a line on a surface. All teams were provided with an identical package of the hardware components necessary to assemble a robot chassis. Two electric motors were also provided along with appropriate motor controller boards. The final major component teams that were provided with was a credit card sized computer board.

Teams were first instructed to assemble the provided components to form a robot chassis. They were then given the task to mount the electric motors and motor controllers in order to drive the robot's wheels. The last part of robot assembly was to install the computer board which provided guidance for the robot. Once installed, each of the electronic components had to be connected in the correct way to enable the robot to function properly.   Student teams were also required to write a Python program to run on the computer board that could continually sample and process input received from infrared sensors and then make adjustments to the robot's wheel speeds as necessary to enable it to follow the path designated by a line. Figure 2 contains images of a fully assembled line following robot.

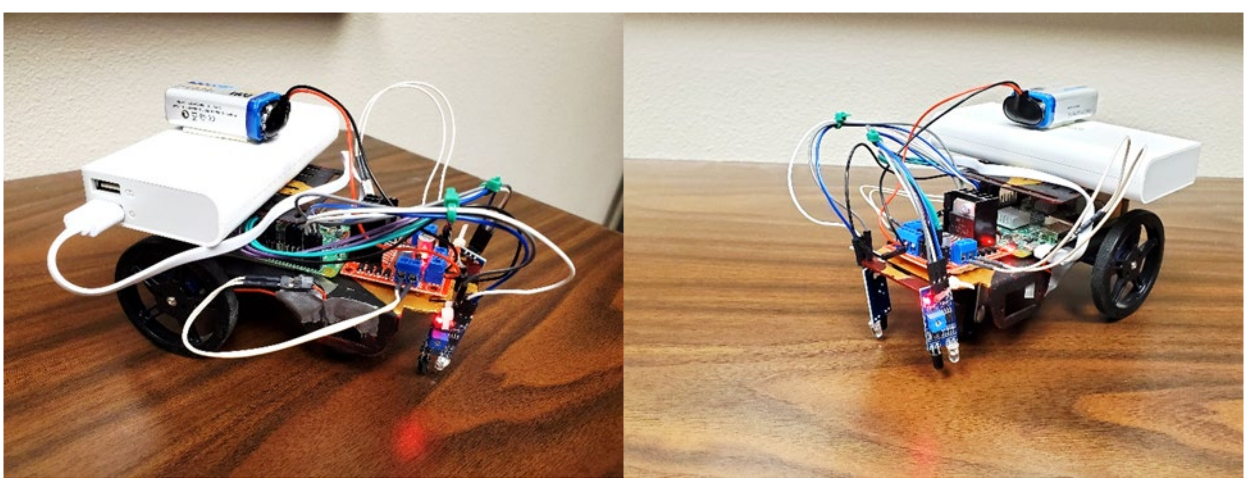

Figure 2. Assembled line following robot.

A competition was held at the end of the semester to determine which team's robot could successfully follow a designated path in the shortest period of time. Two different tracks were included in the competition with varying degrees of complexity in the twists and turns contained in the paths. Teams were allowed multiple attempts to test their robot on each track and were also allowed to make hardware and software adjustments to their robot between attempts. Including an element of competition appeared to serve as a significant motivator for students with teams participating enthusiastically and finding creative ways to get their robots around the track faster.

In the fall of 2020 the introductory course for electrical engineering and computer science students was taught remotely. The design project included in the course was adjusted to accommodate the change in teaching format. Additional material was added to the class focused on the elements of computational thinking with a particular emphasis on algorithm design. The topics of variables, input/output, conditionals, iteration, and modularization were first examined at a conceptual level. Concrete examples were then provided utilizing a block-structured programming environment designed for developing mobile apps. A survey that had been conducted at the start of the semester revealed that many students had little or no prior programming experience. Utilization of a block-structured environment helped to accommodate those students by maintaining an emphasis on concepts rather than syntax.

Material was also covered in class describing the process of designing a program to write a basic algorithm. Example block-structured programs were utilized to demonstrate the process including the specification of both the user interface and the behavior for a basic program. To reinforce the computational thinking topics covered earlier, students were then given exercises to provide practice creating their own programs to perform basic operations such as reading input values, performing a simple calculation, and displaying a result.

A list of several programming project descriptions was then provided, ranging in complexity from a basic calculator app to an app for playing tic-tac-toe. Students were asked to select a specific program upon which to focus as the topic for their project. They then began the algorithm design, implementation, and testing process. Time was allotted in class for project work, providing an opportunity for students to ask questions and receive any necessary assistance. Completed student project submissions included a coded solution for their chosen programming task along with a report describing the algorithmic basis of their solution. The use of a block-structured programming environment appeared to be a good match for the varied student programming backgrounds. Students were especially enthusiastic about the ability to run their coded solutions on mobile devices.

The students in the mechanical engineering section of GEEN 1201 worked two different hands-on projects. The instructor divided students into teams of three to four persons for these projects. The first project was a reverse engineering project, in which students were asked to select a product or an instrument that has a mechanical mechanism and has at least three separate parts. Students disassembled the selected product/instrument and closely reviewed each part of the assembly. Later, the students brainstormed ideas for any improvements or design changes that could help the product function better than its current operation. The next stage of the project involved designing the product in 3D modeling software and using the motion study analysis to check for proper operation of the designed mechanism. The students were asked to select a product which has the least number of individual parts, so the design process will not be tedious. The 3D modeling software used by the students for the project was SolidWorks. Students selected products such as a Rubik's cube, a kick scooter, or a skateboard for this reverse engineering project. Figure 3. Shows one of the student projects who designed a Rubik's cube on SolidWorks.

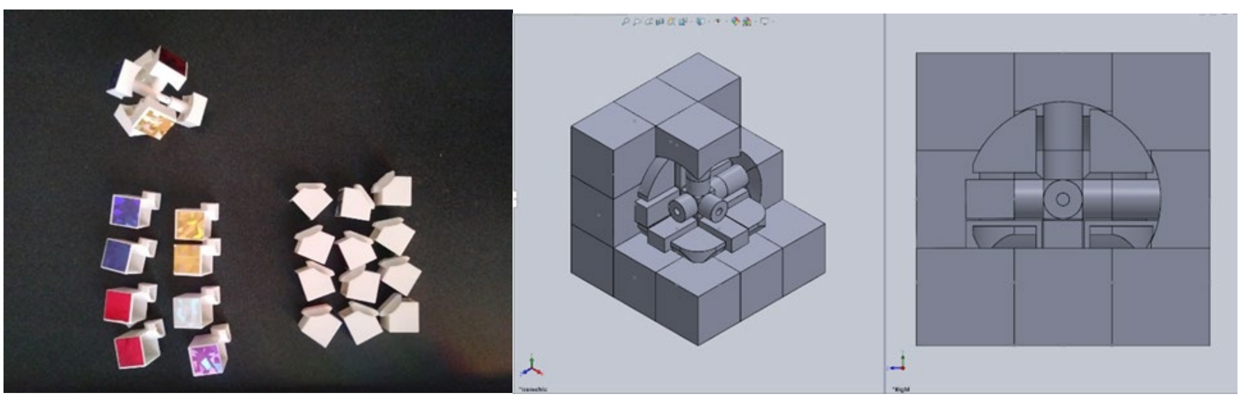

Figure 3. The final Rubik's cube designed by students on SolidWorks.

The second project was a 3D printing design project, in which the students were asked to design a gyroscopic mechanism in SolidWorks and then print the design using an FDM-based (Fused Deposition Modeling) 3D printer. Students were split into teams of four for this project. The students started with the design in SolidWorks by considering the specifications required for the 3D printer. The students were asked to design a product with a limitation that the maximum volume of the designed product should not exceed of 5 cubic inches. Once the design was completed in SolidWorks, students used the basic simulation tool in the software to check for any potential design and assembly errors. Finally, the model was printed using the FDM-based 3D printer. Figure 4. Shows one of the student projects who designed, and 3D printed a gyroscopic mechanism.

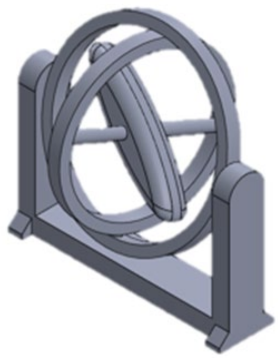

Figure 4. Designed gyroscopic mechanism.

The outcome of the projects indicated that the students showed significant interest in mechanical designing. They also enjoyed working as a group to complete the hands-on projects. As an appreciation for the good work during the projects, the instructor allowed the students to keep the 3D printed parts that they designed. Based on the student comments provided in the student course rating of the instructor, the course was a good introduction to mechanical engineering, with a good balance of hands-on projects and lectures.

Results

Table 2 presents data on the number of students who have dropped from College of Engineering enrollment for each of the sections and years since GEEN 1201 has been offered (fall 2018), in the three departments discussed here. These data are based upon current student status after the last semester (fall 2020). Those no longer in engineering include students who are no longer enrolled at Texas A&M University-Kingsville, as well as students still here, but who have changed to a major outside of the Frank H. Dotterweich College of Engineering. Therefore, the students who were in the fall 2018 cohort are now juniors and the students who were in the fall 2019 cohort are now sophomores. The data in Table 2 indicate that a wide percent range (23 to 71%) for students who are no longer in an engineering program, and a similarly wide percentage range (25% to 71%) of Hispanic students are no longer in engineering, based on this data set of three years and three course sections. However, the data also indicate that the percentage of students no longer in engineering has dropped significantly from 2018 to 2020. Specifically, in the chemical engineering section, the percentage of students no longer in engineering is 41% for the 2018 and 2019 cohorts, and then it dropped to 23% for the 2020 cohort. In electrical engineering and computer science, the percentage no longer in engineering is 71% for the 2018 cohort, and it dropped to 27% for the 2020 cohort. In mechanical engineering, the percentage no longer in engineering is close to 50% for both the 2018 and 2019 cohorts, and then it dropped to 27% for the 2020 cohort. The data indicate a correlation between the inclusion of the grant-sponsored design projects in the GEEN 1201 courses and the retention levels over the last three years of GEEN 1201. An additional factor not separately accounted for in this analysis is the normal attrition of first-year students in our engineering program.

Table 2. Percentage of students in the GEEN 1201 course that are no longer attending Texas A&M University-Kingsville or are no longer pursuing an engineering major

	Course Section (by engineering discipline)					
	Chemical and Natural Gas		Electrical and Computer Science		Mechanical	
	All students	Hispanic only	All students	Hispanic only	All students	Hispanic only
Fall 2018	41% (17)	36% (11)	71% (21)	71% (17)	48% (23)	31% (16)
Fall 2019	41% (17)	50% (14)	53% (15)	50% (12)	53% (17)	64% (11)
Fall 2020	23% (13)	33% (9)	27% (22)	25% (12)	27% (11)	33% (9)

‡ -- number of students upon which statistic is based given in parentheses
Source: [2]

The NSF grant external evaluator noted the following results for the GEEN 1201 courses from fall 2019, based on interviews with course peer mentors and faculty instructors as reported in the first annual report [9]:

- Peer mentors reported that students in the section of GEEN 1201 in which a team project in robotics had been implemented increased their confidence in pursuing an engineering degree and, as a related construct, their sense of belonging in the engineering field.
- Psychological development of students [10] was reported by each faculty as learning collaborative and cooperative processes, enjoying the task, and an associated sense of identification with engineering processes.
- The patterns observed by the peer mentors were also mentioned by the faculty responsible for the learning by design pilot courses. Notation of similar impacts by a different group of observers and across three courses in which different learning by design projects were enacted confirms the social development assertions made by the peer mentors.
- In addition to social development challenges, the faculty members also observed students engage with and learn from the intellectual challenges of the learning by design activities. This was the case in all three courses. While the instructors described the learning in more detail than the peer mentors had, the basic premise was the same. The students'

experience combined application of theory and practical skills in the completion of a task that required analysis, design, experimentation, trouble-shooting, and refining processes to reach a goal. The result was learning in each realm.

Conclusions and Future Direction

The addition of a design project experience appears to have a positive effect on first-year student retention in engineering, to a similar extent amongst Hispanics as compared to all students registered in the subject course. The greatest change in retention percentages after inclusion of the design experience occurred in the electrical engineering and computer science section of the course. Future offerings of the GEEN 1201 sections taught by the authors will benefit from the previous offering of the course. Several suggestions for design project experience improvements arose from the 2019 offerings of the course. In particular, both the chemical and electrical engineering instructors noted that the design experience should be allotted a longer period of time, and the course lecture material leading into the design should be slated for delivery earlier in the semester. This approach would allow more time for students to understand design concepts as they consider implementing them in the project. Additionally, the chemical engineering section instructor recommended including in the course schedule a one-day engineering challenge activity early in the semester, as a tool to demonstrate brainstorming and testing concepts of the design process. These changes were implemented by the instructors in the 2020 course offering.

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