ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #37117

Work in Progress: Experiences Utilizing Engineering Design Projects in Early Curricular Engineering Courses at a Hispanic-serving Institution

David Hicks

David Hicks is an Associate Professor in the Electrical Engineering and Computer Science Department at Texas A&M University-Kingsville. Previously 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.

Michael Preuss (Co-founder and Lead Consultant)

Michael Preuss, EdD, is the Co-founder and Lead Consultant for Exquiri Consulting, LLC. His primary focus is providing assistance to grant project teams in planning and development, through external evaluation, and as publication support. Most of his work is on STEM education and advancement projects and completed for Minority-Serving Institutions. He also conducts research regarding higher education focused on the needs and interests of underserved populations and advancing understanding of Minority-Serving Institutions.

Matthew Lucian Alexander (Associate Professor)

Dr. Matthew is an associate professor in Chemical Engineering at Texas A&M University-Kingsville

Rajashekar Reddy Mogiligidda (Lecturer 1)

Mahesh Hosur

Work in Progress: Experiences Utilizing Engineering Design Projects in Early Curricular Engineering Courses at a Hispanic-serving Institution

Introduction

The continuing shortage of students that successfully complete engineering related education programs and its potential serious negative economic impacts have been well documented. At the same time, the significant underrepresentation of minorities and women in the STEM workforce continues. An ongoing NSF sponsored project at Texas A&M University-Kingsville (TAMUK), a Hispanic Serving Institution (HSI), has focused on increasing the rates of retention and persistence among students in the College of Engineering, especially for minority students and those underrepresented in engineering fields. Emphasis has been placed on courses taken by students early in the engineering curricula. In particular the first-year introductory engineering courses taught within three departments have been augmented to include an engaging, team-based, hands-on engineering design project.

Collaborative design projects are already included in the curriculum of engineering programs at many US universities. However, most often these take the form of a capstone project to be conducted by upper level (senior) students as they prepare to complete their undergraduate studies. The inclusion of an engineering design experience much earlier in the curriculum can benefit students in a variety of ways including helping them to understand the important linkage between the foundational math and science courses they are required to take and the engineering discipline they are planning to study [1, 7, 8]. This has led to a growing number of universities integrating design experiences into earlier semesters of their engineering programs [6].

The first-year introductory engineering course taken by engineering students at TAMUK is titled "Engineering as a Career" (GEEN 1201). Each department within the college of engineering offers its own section of the GEEN 1201 course that is specifically designed for its majors. With support from the NSF grant, the GEEN 1201 sections for three departments within the College of Engineering, Chemical and Natural Gas Engineering, Mechanical Engineering, and Electrical Engineering and Computer Science, have been enhanced to include team-based design projects. This paper describes the design projects that have been utilized in these courses with an emphasis on the most recent offerings including improvements that were made based on previous course feedback.

As an HSI designated university, a significant percentage of the student population at TAMUK is Hispanic. This is also reflected in the composition of students in the College of Engineering. Table 1 provides a detailed look at the percentage of Hispanic/Latinx students in each of the enhanced first-year introductory engineering courses taught during the past four years with a range in percent Hispanic/Latinx students of 33% to 81% and an average of 70% which is similar to the percent in the overall student population of the institution, 74.7% in fall of 2021 [5].

Table 1

Percentage of Hispanic/Latinx students in first-year GEEN 1201 courses

Semester	percentage of Hispanic students in each course		
	Chemical and Natural Gas Engineering	Electrical Engineering and Computer Science	Mechanical Engineering
Fall 2018	65% (17)*	81% (21)	70% (23)
Fall 2019	82% (17)	75% (16)	65% (17)
Fall 2020	69% (13)	55% (22)	82% (11)
Fall 2021	73% (11)	33% (9)	80% (15)

* total number of students in course given within parentheses. Source: [2]

In the following section of the paper the design projects utilized in each of the enhanced introductory engineering courses are described. A results section follows that presents and discusses preliminary results and observations of the most recent course offerings along with a comparison to results from previous course iterations. This includes survey results measuring students' perceptions of their abilities, confidence, and knowledge in general engineering problem solving tasks both before and after the augmented introductory engineering courses. The final section provides a look at future research and conclusion.

Implementation of Design in the First-Year

In this section, the hands-on design projects that were utilized in the fall 2021 semester offering of the enhanced introductory GEEN 1201 courses for each of the three departments are reported. A detailed description of the enhanced introductory courses taught during previous semesters can be found in [3].

Chemical and Natural Gas Engineering: The hands-on design project assigned to the student teams in the 2021 offering of the chemical and natural gas engineering section of GEEN 1201 consisted of the development of a prototype device for on-demand water purification. The students were instructed that the water purification step should involve the destruction or removal of surrogate organic contaminants-methanol, ethanol, or isopropanol. These chemicals were chosen by the instructor for this project due to their ease in determination of aqueous concentration by refractive index methods.

The performance requirements for the prototype were a water flow rate of 100 to 300 milliliters per minute, to be sustained by their device for a period of at least 10 to 15 minutes. The contaminant removal objective was for each team to decrease the designated alcohol from an initial level of 5 to 10 volume percent to a couple volume percent. Because of the limited time allotted to the project during the semester (approximately 6 weeks), the instructor gave the specific problem definition to the students rather than having them perform their own problem definition based upon a more generic needs statement.

The instructor provided each student team with low-cost materials with which they could form a simple treatment device, namely a container using two-inch PVC pipe and endcaps, and treatment materials including filter paper, sand, gravel, and activated carbon. Additional equipment, such as a peristaltic pump and a digital refractometer, were available for the students to use. The teams constructed and tested their treatment devices in the chemical engineering unit operations laboratory. Typical student constructed devices are shown in Figure 1.

Figure 1. Typical water treatment devices developed by students.

The treatment testing performed by the students provided hands-on experience in basic fluids concepts such as flow under gravitational force, static head, and flow through porous media. The 2021 offering of this GEEN 1201 course was the third year that this particular design project was utilized in the course. In 2021, the students were challenged by the instructor to use relevant technical books and literature to identify applicable treatment technologies for their respective contaminants. Students identified adsorption, aeration, chemical oxidation, and distillation or boiling as appropriate methods, however all groups in this third-year cohort gravitated towards testing only adsorption during their laboratory testing opportunity.

Electrical Engineering and Computer Science: In the fall semester of 2021, the GEEN 1201 introductory course taught to Electrical Engineering and Computer Science students incorporated a collaborative robot building project designed to provide hands-on experience and further engagement with the course content. The robot was required to be capable of following a path represented by a dark line laid out on a light background. Student teams of between 2 and 4 persons were given the components needed to build a 3-wheel chassis to serve as the base of their robot. Teams were also provided with two motors to drive the robot wheels, a motor controller, and a credit card sized computer board (Raspberry Pi). A power bank was supplied to provide power for the logic boards along with a 9-volt battery to power the drive motors. Students were also provided with infrared sensors to design a guidance system for the robot.

The student teams were first tasked with assembling the base chassis for their robot including the wheel assemblies. Next, they were instructed to mount their guidance computer and motor controller boards securely to the chassis. Teams were then supplied with jumper wires to make the appropriate connections between each of the digital components and to connect power outputs to the robot drive motors. Following that, students were required to determine an appropriate way to mount the power bank and 9-volt battery to their chassis without causing the robot to become top heavy or unstable. The final stage of assembly was determination of appropriate locations on the robot to place the infrared sensors in order to gather the input needed for guidance purposes.

The student teams also wrote a guidance program for their robot in Python which ran on the Raspberry Pi board. The program was to read and process input signals from the infrared sensors to determine the position of the robot relative to the path it should follow. Adjustments to the robot's direction and speed were to be made by varying the signals sent from the Raspberry Pi board to the motor controller. Based on experiences from a previous course offering, additional content and examples of the Python programming language were provided. Students were given approximately 4 weeks to complete their projects. Figure 2 illustrates a fully assembled line-following robot as well as one of the tracks used for testing.

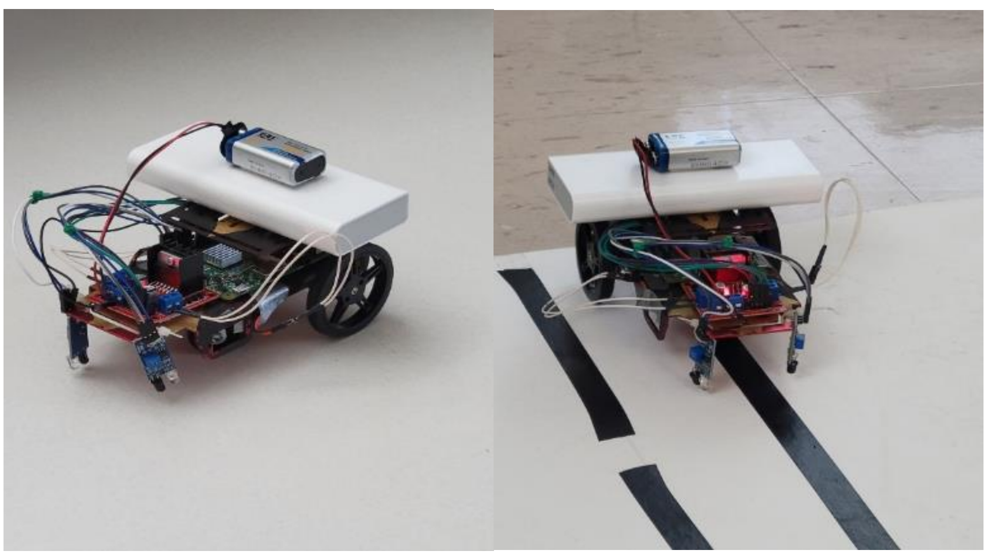

Figure 2. Assembled line following robot (left); robot following track (right).

A competition was held at the end of the semester to determine which team's robot could successfully follow a path from start to finish in the shortest amount of time. Two tracks were used for the competition, one with a track laid out in a standard figure 8 pattern, the other with a track containing a series of random twists and turns. Teams were allowed time to complete several runs on each track, including making hardware and software adjustments between runs to improve their performance. The competition element was a significant motivator for students leading to enthusiastic participation and the design of creative ways for teams to get their robot around the track more quickly.

Mechanical Engineering: The Mechanical and Industrial Engineering section of the GEEN 1201 course for the fall 2021 semester included a hands-on project which required the student groups to model a 3D mechanism and then later print parts using an FDM technology 3D printer. Students were instructed to design parts with a limitation that the total volume of the final design does not exceed 5 cubic inches. Also, the design selected was to have at least 4 different parts that had a minimum clearance of 0.05 inches between parts. These limitations were intended for students to make a scaled down version of a larger mechanism.

The student teams were given a set of instructions for and a list of limitations of 3D printing and 3D modeling. They were provided approximately 4 weeks to complete the design and print it. Improvements and updates made to the design project over prior years included the use of interference detection while 3D modeling. Additional content and examples were given pertaining to the clearances and supports for 3D printing.

Students were given access to SolidWorks 3D modeling which they used to design their mechanisms. A portable FDM 3D printer was available for students to use and gain hands-on experience with 3D printing. Figure 3 shows a Ferris Wheel design that was developed by students in the fall 2021 semester course offering which was later 3D printed.

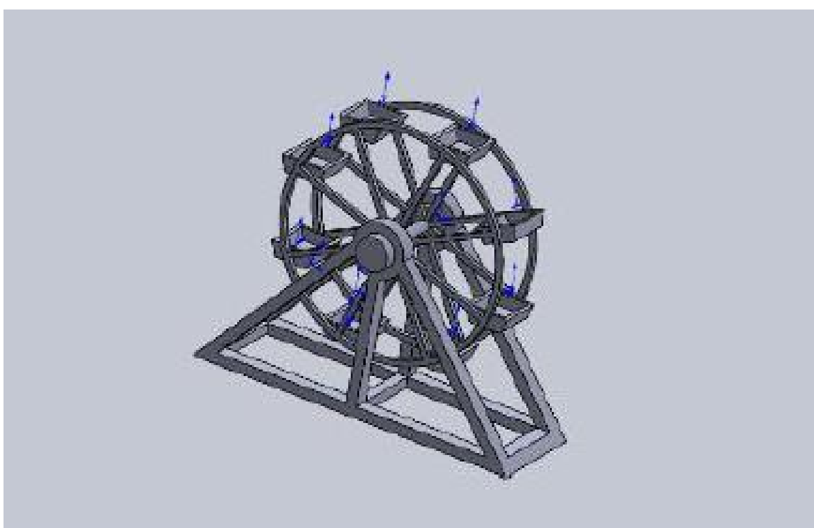

Figure3. Ferris Wheel design developed by students.

Results

Pre- and post-participation surveys regarding the hands-on projects were conducted in the three sections of GEEN 1201 as were institutional end-of-course surveys. Table 2 contains demographic information from the pre-participation responses, for the College of Engineering (CoE), and for the institution. The post-participation survey did not request demographic information as it was assumed informants on that instrument would correspond to or be a subset of the pre-participation sample. That did not prove to be the case as response rates were low and there were a limited number of parties who responded to both surveys. For example, two of four informants in the H1 section submitted responses to both surveys.

The pre-instruction data indicates the sample skewed male and toward individuals who identified as White in comparison to TAMUK's overall student population. This was especially the case in the H1 section which focused on computer science. Yet, the sample is more representative of the engineering majors when considering gender. Notably, the percentage of females enrolled in the CoE and the GEEN sections was similar and high when compared to the percentage employed in engineering where there is a longstanding underrepresentation of females [4]. Thus, success in encouraging interest in and commitment to engineering majors among females at the university, a possible ancillary of the curriculum revisions being undertaken, would be a very positive outcome for the project.

Table 2

Gender, Ethnicity, and Racial Identity Reports by Informants

Group	**Period**	***n***	**Gender**		**Ethnicity**		**Racial Identity**		
			Female	*Male*	*Hispanic*	*Non-Hisp*	*Hisp/Ltn*	*NAAN*	*White*
TAMUK	2021	5085	50.4%	49.6%	74.7%	25.3%	74.7%	Unknn	14.7%
CoE	2021	1213	20.0%	80.0%	-	-	-	-	-
GEEN 1201	Pre	19	21.1%	78.9%	73.7%	26.3%	52.6%	6.3%	42.1%
Section A1 (Chem/NG Eng)	Pre	5	40%	60%	60%	40%	40%	-	60%
	Post	-	-	-	-	-	-	-	-
Section H1 (Elec Eng/CS)	Pre	4	-	100%	50%	50%	50%	-	50%
	Post	2	-	100%	50%	50%	50%	-	50%
Section M1 (Mech Eng)	Pre	10	20%	80%	90%	10%	60%	10%	30%
	Post	-	-	-	-	-	-	-	-

Note: TAMUK data obtained from: https://www.tamuk.edu/oira/institutional-data/Interactive-Campus-Data.html; NAAN = Native American/Alaska Native.

Seven general engineering questions were asked of informants in each course. A ten-point scale was used in responses with students instructed to submit a rating of zero for "100% disagreement" and ten for "100% agreement." A summary of the results appears in Table 3. Since the sample is small and some students did not respond to all the questions, the informant groups, especially for the post-instruction survey, were too small to meet the assumptions for meaningful statistical analysis if disaggregated by section or demographic characteristic. Analyses reported are the product of unpaired *t* tests.

Table 3

Cohort Level Responses to General Engineering Questions

Prompt	Period	*n*	Mean	Median	SD
I am confident in my ability to work as a team member on an engineering project.	Pre	17	6.76	7	2.16
	Post	11	8.82**	9	1.19
I know the basics of the engineering design process.	Pre	17	5.43	6	2.25
	Post	11	9.55***	10	0.78
I know how to do engineering experimentation.	Pre	17	4.21	5	2.58
	Post	11	8.27***	9	1.71
I am NOT familiar with ways to analyze engineering data.	Pre	16	3.77	3.5	2.55
	Post	10	3.5	3.5	3.04
I do NOT know how engineers do problem solving.	Pre	15	3.25	3	1.96
	Post	8	3.75	2.5	3.38
I am very interested in becoming an engineer.	Pre	17	8.64	9	1.36
	Post	11	9.64*	10	0.77
I am NOT certain that engineering is for me.	Pre	16	2.42	2	2.21
	Post	10	0.80*	0.50	0.87

Note: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

Informant responses included statistically significant differences pre- to post-instruction. These were for confidence in ability to work as a member of a team on an engineering project, knowing the basics of the engineering design process, knowing how to do engineering experimentation, interest in becoming an engineer, and certainty that engineering was the field for the individual to pursue. These findings are notable for the high level of significance for the first three items and the presence of a significant result for the last two. The penultimate and ultimate items showed a positive inclination toward engineering on the pre-instruction survey. That the increase post-instruction occurred at a significant level suggests substantial impact from the instruction received.

Table 4 addresses impacts on discipline-specific understanding, skill, ability, and interest. The response counts for the A1 and H1 sections had too few cases to support analysis, with informant ranges of 4 to 5 and 1 to 2 respectively for the courses. Thus, only the prompts are listed for sections A1 and H1. The M1 section had sufficient informants on both the pre- and post-instruction survey to support analysis. A ten-point scale was used in responses with students instructed to submit a rating of zero for "no understanding" and ten for "full understanding."

Table 4

Prompts and Responses to Discipline-Specific Questions

A1 Section	*H1 Section*
I understand how different materials can be used to remove offensive chemicals in water treatment systems.	I can build a simple chassis for a mobile robot.
I can design a basic water treatment system.	I can mount electric motors and associated wiring to a robot chassis.

I DO NOT know how to use a peristaltic pump.	I have worked with a computer board for a small robot.
I know how to complete refractive index readings with water samples.	I can write a program in Python to process data for guiding a robot.
I can explain the need for a prototype-test-repeat approach in engineering design.	I find it motivating to compete with classmates to see whose design project works best.

M1 Section

Prompt	**Period**	***n***	**Mean**	**Median**	**SD**
I understand the reverse engineering process.	Pre	8	4.375	4	3.24
	Post	5	9.60**	10	0.80
I CANNOT use 3D modeling software to design a mechanism.	Pre	7	3.29	4	1.91
	Post	4	0.60*	0.50	0.83
I know how to use 3D modeling software to do motion study analysis.	Pre	8	2.88	3	2.37
	Post	5	6.4*	7	3.38
I have designed a product that fit a predefined set of specifications.	Pre	7	4.57	2	4.20
	Post	5	9.0*	10	1.26
I have used 3D modeling software to complete a design project.	Pre	8	2.88	2	3.06
	Post	5	9.20***	10	0.98
I have used 3D modeling software to complete assembly interference detection.	Pre	7	2.00	1	2.14
	Post	5	9.20***	10	1.17
I do NOT find design of mechanisms interesting.	Pre	6	1.5	1	2.06
	Post	5	0.20*	0	0.40
I see real-world applications for things I learned about reverse engineering.	Post	5	8.0	10	4.00^{+}
I do NOT see real world applications for things I learned about 3D modeling.	Post	4	0.2	0	0.43

Note: * $p < .05$, ** $p < .01$, *** $p < .001$; $^{+}$ = possible confusion regarding the rating scale for one student which significantly increased the standard deviation.

The learning statements listed in Table 4 were developed from the objectives for the hands-on projects. The intention was to measure whether the implementation of the projects achieved the intended goals. Statistical analysis of responses for sections A1 and H1 was not warranted. However, there were large differences in the responses pre- to post-participation, for example the largest change in mean for section A1 was 7.50 points on an eleven-point scale (0-10) and the smallest was 5.10. The range of ratings in H1 was as large as zero to ten pre- to post-participation. Overall, the only mean that did not move in the desired direction was for operation of a peristaltic pump for section A1, decreasing by 0.4 points although there was a large reduction in standard deviation. This was a technical process that could have been performed by a limited count of students in each group. Even with these caveats, there is a strong and consistent pattern of reported learning. Five of six means went up substantially for the A1 section, responses in the H1 section (only two informants) were strongly higher post-instruction, and all six discipline-specific learning queries for section M1 registered statistically significant differences in reported understanding.

Table 5 presents information from post-instruction queries about learning, interest, and confidence. The questions were only present on the post-participation instrument. A ten-point scale was used for responses with students instructed to submit a rating of zero for “100%

disagreement" and ten for "100% agreement." As noted above, the informant group was small and could not support disaggregation by course section or other characteristics.

Table 5

Responses to Learning, Interest, and Confidence Queries

Prompt	*n*	Mean	Median	SD
I learned about designing a system, component, or process to fill a recognized need.	11	9.27	10	1.21
I learned how to conduct experimentation in engineering.	11	8.45	10	1.78
I learned NOTHING about analyzing data and interpreting the results.	9	1.0	0.5	1.32
I learned an engineering design process.	11	9.0	10	1.41
I learned problem solving patterns applicable to engineering.	11	8.82	10	2.12
I learned NOTHING about writing for engineering during the process of creating the project report.	9	1.44	0	1.89
I learned what is relevant for an engineering presentation while preparing my team's project presentation.	11	8.45	10	1.92
The hands-on project increased my interest in engineering.	11	9.55	10	1.16
The hands-on project increased my confidence that I can be an engineer.	11	9.0	10	1.41

The post-instruction responses to the learning, interest, and confidence questions show a strong positive trend (Table 5). All means, when ratings for negatively phrased queries are inverted, are at or above 8.45 on an eleven-point scale with standard deviations ranging from 1.16 to 2.12. A simple summary is that informants reported substantial learning in every area queried, a strong increase in interest in engineering based on the hands-on projects, and increased confidence in personal ability to become an engineer resulting from the hands-on experiences.

Students also reported increased insight post-participation. Informants in the A1 and H1 sections were asked if they saw "real-world application for the things…learned" from the hands-on project. Responses to these questions were positive with the mean response above 8.0. The same result was found for section M1 (details appear in Table 4).

Institution-facilitated end-of-course surveys confirmed the GEEN 1201 students saw the team project as a highlight of the course and found it to be helpful for learning about the engineering design process. Completing the task in a group was also noted as beneficial.

Interest in the topics chosen for the hands-on learning projects and effective process facilitation may have contributed to the positive outcomes. Post-instruction questions regarding interest in the project topic were worded in the negative for each section but student ratings placed interest near or above the upper quartile in each course section. A set of responses to queries about the learning environment and process facilitation, such as were instructions comprehensive and easy to follow, was the grading pattern clear, was the instructor available to provide guidance, were necessary supplies and space readily available, resulted in uniform agreement at the upper fifth of the scale. This speaks well of the planning and execution of the hands-on labs, a characteristic that would likely have contributed to the learning achieved, increased interest in engineering, and increases in personal confidence.

Conclusion and Future Directions

The hands-on projects implemented proved to be of interest to the students and effective. Students saw them as a highlight of the course and reported significant advancement resulting from them. This occurred as increases in confidence in ability to work as a member of a team on an engineering project, knowing the basics of the engineering design process, knowing how to conduct engineering experimentation, interest in becoming an engineer, and certainty that engineering was the field for the individual to pursue. It was also the case for the discipline-specific instructional goals in each section of the course and the ability to perceive "real-world application for the things…learned" from the hands-on activity. While this paper considers one semester of activity with a limited number of participants, these outcomes suggest substantial efficacy in and potential for student benefit from continued implementation of practical experiential learning in the GEEN 1201 courses for all students.

Verification of these findings will be necessary through continued use of the hands-on projects. This will be completed in coming semesters.

This work was funded by the National Science Foundation Award #1928611. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

[1] Bucks, G. W., & Ossman, K. A., & Kastner, J., & Boerio, F. J., & Torsella, J. A. (2014, June), First-Year Engineering Courses' Effect on Retention and Student Engagement Paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana. 10.18260/1-2--20499
[2] Information request response from TAMUK Office of Institutional Research and Assessment (https://www.tamuk.edu/oira/index.html) on January 26, 2022.
[3] Alexander, M. L., & Mogiligidda, R. R., & Hicks, D. (2021, July), Work in Progress: Inclusion of an Engineering Design Experience in Freshman Introductory Engineering Courses at a Hispanic-serving Institution Paper presented at 2021 ASEE Virtual Annual Conference Content Access, Virtual Conference.
[4] National Science Foundation. (April 29, 2021). Women, minorities, and persons with disabilities in science and engineering. https://ncses.nsf.gov/pubs/nsf21321
[5] Texas A&M University – Kingsville. (n.d.). Interactive campus data. https://www.tamuk.edu/oira/institutional-data/Interactive-Campus-Data.html
[6] Prendergast, L., & Etkina, E. (2014, June), Review of a First-Year Engineering Design Course Paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana. 10.18260/1-2—22987

[7] Meyers, K., Cripe, K. (2015) “Prior educational experience and gender influences on perceptions of a first-year engineering design project.” International Journal of Engineering Education, 31 (5): 1214-1225.
[8] Prince, S.P., Tarazkar, Y., (2013) “Mechanical Engineering Design Experience for Hispanic and Low Income Students.” ASEE Annual Conference and Exposition, Conference Proceedings, 2013.