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Using Projects to Improve Student Engagement and Retention in a First-Year Engineering Course

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Using Projects to Improve Student Engagement and Retention in a First-Year Engineering Course

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Abstract

The first-year engineering course at the University of Mary Hardin-Baylor (UMHB) was redesigned for the Fall 2022 semester to improve student engagement and retention in the engineering program. The course design centered around an individual design project, with supporting modules to prepare students for the project. Student feedback (in the form of student reflections) provided insight into how students interacted with the project. Despite being an individual project, many students described community building that occurred through collaboration. Students also described a sense of accomplishment from completing a difficult, open-ended design problem. The redesigned course has been offered in two semesters (Fall 2022, Fall 2023), and the retention rates for students enrolled in these courses increased by 15-20% when compared to retention rates for the previous two years (Fall 2020, Fall 2021). Future improvements to the project will focus on further emphasizing the engineering design method and adjusting the project scope to engage an academically diverse student population.

Introduction

The engineering program at the University of Mary-Hardin Baylor was established in 2017 and received ABET accreditation in 2022. UMHB has a high acceptance rate, and any admitted student can select engineering for their major. This combination of factors has led to an academically diverse engineering student population which, in turn, has contributed to low retention rates (approximately 40-60%) in UMHB engineering students between the fall and spring semesters of their first year. Previous studies suggest that incorporating hands-on projects early in the curriculum can increase student retention and engagement across a range of contexts[1-9], and specifically at a small institution with a limited enrollment like UMHB[10]. With this in mind, the engineering faculty sought to implement a hands-on project into the first-year engineering course at UMHB. This paper describes the implementation of this project, including motivation, project selection, course redesign, and assessment.

First Year Course Redesign

As mentioned in the introduction, the UMHB engineering faculty sought to implement a hands-on project into the first-semester engineering course (ENGR 1310: Introduction to Engineering). All engineering students take this course before specializing in mechanical engineering and electrical engineering by their third year. Before Fall 2022, ENGR 1310 served as a broad introductory course,

covering a wide range of topics in a lecture format. The faculty saw this course as an opportunity to more effectively engage students and address retention in first-year students in the engineering program.

During the planning stages, the engineering faculty established four themes for the project:

- The project should be *challenging*. Students would understand the high level of expectation for effort in engineering classes, while simultaneously being encouraged to solve a difficult problem.
- The project should be *open-ended*. Students would use the engineering design process to create a unique design, with no pre-defined solutions.
- The project should be *hands-on.* Students would utilize the maker space at the UMHB Engineering Design Building to gain hands-on experience with hardware and software.
- The project should be *competitive*. Basing the project around a competition would create a sense of community and comradery among the students, while also providing extra motivation for the highest-achieving students.

The faculty decided to implement the project in ENGR 1310 during the Fall 2022 semester. The retention rate for first-year engineering students had dropped over the previous two years, and a different instructor was assigned to teach ENGR 1310 (for the first time). The instructor was tasked with developing a project that met the four criteria listed above and implementing the project in the ENGR 1310 curriculum.

Design Project Description

The instructor decided to implement a robot vehicle design challenge. Students were tasked with designing/building/testing a small robotic vehicle that could navigate a 100 ft. course with minor obstacles. The students were not allowed to purchase an RC car or a kit as a starting point, which forced them to assemble and build their vehicle from scratch using parts they could order from Amazon (wheels, motors, etc.) on a $35 budget. The students could use an Arduino (at no cost), and they had to program the vehicle to navigate the course (either autonomously or through wireless control). The project culminated in a design showcase, where each student tested their vehicles in succession. The faculty gave three awards at the event (highest score, most innovative design, most aesthetic design) to further incentivize students to think critically about their designs.

This project met all four criteria established by the faculty. Most of the students purchased geared motors and motor drivers from Amazon to power their vehicle. Students could choose a piece of ¼" thick sheet of plywood or a 1/8” thick sheet of plexiglass for a vehicle chassis, which they had to cut/shape using the tools in the Maker Space. Some of the students also purchased small Bluetooth adapters, which allowed the vehicle to be controlled using a smartphone app. Even though the students generated initial designs and selected a preliminary design using a decision matrix, many students altered their designs as they saw other students complete the project. At the project showcase, 11 out of 34 vehicles successfully completed the 100 ft. course, and an additional 16 vehicles

completed part of the course. Figure 1 shows one of the vehicles created by the students.

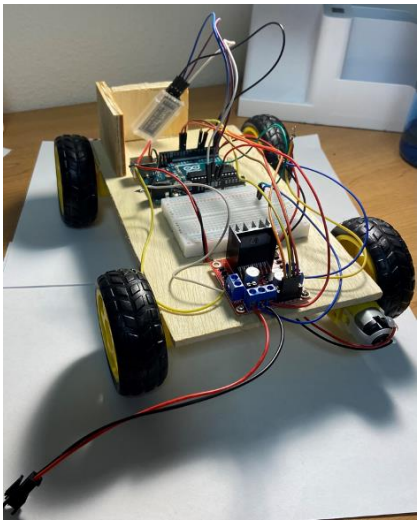

Figure 1. Example vehicle from the Fall 2022 project.

The same project, with minor modifications, was used when the course was offered again in Fall 2023. In this second iteration of the project, students had to design a vehicle that could grab or push a 1 lb. bag of grain for 30 ft. The budget was increased to $40, and the instructor gave more initial guidance on components that could be used in the design (geared motors, servo motors, motor drivers, etc.) Students were also actively encouraged to use rapid prototyping in their designs. At the design showcase, 12 of 48 vehicles successfully completed all the assigned tasks, and 23 additional vehicles performed some of the tasks. Figure 2 shows two students testing their vehicle at the design showcase in November 2023.

Figure 2. Two students test their robot vehicles during the Fall 2023 Design Showcase.

Course Modifications

The ENGR 1310 curriculum needed to be restructured to support students as they worked on their projects. Prior to Fall 2022, the ENGR 1310 curriculum had three main components: an introduction to the engineering profession, an introduction to engineering mathematics, and a brief discussion of engineering fundamentals (statics, dynamics, and electrical circuits.) The redesigned course covered some of the same material, with some elements de-emphasized (mathematics) and additional material added to support the design project. Figure 1 compares the ENGR 1310 course schedule Fall 2021 and Fall 2022.

Week No	Week beginning	Description	Reading
1	Aug 09	Introduction to Engineering Engineering Functions & Majors Statistical Profile of the Profession Global & International Engineering Future Challenges	Ch 1 – 5
2	Aug 16	Ethics Units and Conversions	Ch 14 Ch 15
3	Aug 23	Math Review—Algebra Math Review—Trigonometry	Ch 16
4	Aug 30	Math Review—Geometry Math Review—Complex Numbers	Ch 16
5	Sep 6	M: Labor Day Holiday (No Class) W: Review for Exam I **F: Exam I**	Chs1-5, 14 & 16
6	Sep 13	Math Review—Calculus	Ch 16
7	Sep 20	Math Review—Calculus	Ch 16
8	Sep 27	Math Review—Probability & Statistics	Ch 16
9	Oct 4	W: Review for Exam II **F: Exam II**	Ch 16
10	Oct 11	Engineering Fundamentals—Statics	Ch 17, 493 - 499
11	Oct 18	Engineering Fundamentals—Statics Engineering Fundamentals—Dynamics	Ch 17, 493 - 499
12	Oct 25	Engineering Fundamentals—Dynamics	Ch 17, 500 - 505
13	Nov 1	Engineering Fundamentals—Thermodynamics	Ch 17, 506 - 516
14	Nov 8	Engineering Fundamentals—Electrical Circuits	Ch 17, 516 - 524
15	Nov 15	M [11/13]: Review (Last Day of Class) **F [11/19]: Final Exam 8-10 am**	All chapters covered

Week	Dates	Topics	Individual Project
1	8/8, 8/10, 8/12	Course Introduction, What Do Engineers Do?, Succeeding in Engineering	
2	8/15, 8/17, 8/19	Units and Dimension, Ethics	Maker Space Tour
3	8/22, 8/24, 8/26	The Engineering Design Process, Technical Writing, Presentation Skills	
4	8/29, 9/31, 9/2	Mathematics	Project Definition
5	9/7, 9/9	Mathematics, Electrical Engineering	Preliminary Design Sketches
6	9/12, 9/14, 9/16	Electrical Engineering, Circuits	
7	9/19, 9/21, 9/23	Circuits, Programming and Arduinos	Preliminary Design Report
8	9/26, 9/28, 9/30	Programming and Arduinos	
9	10/3, 10/5, 10/7	Review, **Mid-Term Exam**	Order Parts
10	10/10, 10/12, 10/14	Advanced Mathematics (Calculus, Probability, Statistics)	
11	10/17, 10/19, 10/21	Overview of Statics	Assembly/Iteration
12	10/24, 10/26, 10/28	Overview of Statics	
13	10/31, 11/2, 11/4	Overview of Dynamics	Testing
14	11/7, 11/9, 11/11	Overview of Thermodynamics	
15	11/14, 11/16, 11/18	Review, Final Exam	Final Report

Figure 1. Comparison of Fall 2021 (left) and Fall 2022 (right) course schedules for ENGR 1310

The content that was added to the curriculum during the course redesign included:

- A tour of UMHB engineering facilities. During the second week of classes, the students took a tour of the Engineering Design Building, including the Maker Space. Students talked with the maker space supervisor to discuss how they could use the maker space to build their projects.
- A module on the engineering design process. Before the students were given their project definition, students spent two classes learning about the engineering design process (research, ideation, design selection, prototyping, testing, iteration) to understand how they should approach the design project.
- A module on technical writing. Because ENGR 1310 is a first-semester course, most of the

students had not yet taken a college level composition course. The module focused on the importance of written communication for engineers and technical writing basics. The students would practice these skills as they completed project reports throughout the semester.

- A module on electrical circuit basics. The students needed to wire the electronics on their vehicles, and the electrical circuit module (weeks 5-6) taught students how to use a multimeter, how to build complete circuits, and how to connect components in series and parallel.
- A module on microcontroller basics. Students could use an Arduino on their project, but most had never used a microcontroller. The module focused on hands-on activities where the students familiarized themselves with the Arduino programming interface (uploading/editing sketches using the C programming language) and connecting circuits to the analog and digital output pins.

Table 1 lists the assignments used to guide students through the project. These assignments were also used to assess students as part of their final grade in the course (30% of their final course grade). For the Fall 2022 semester, the first assignment (10% of the project grade) was a short report containing research and preliminary sketches of different vehicle designs. Two weeks later, the students submitted a preliminary design report (20% of their project grade). For the preliminary design report, students used a decision matrix to select between three of their design ideas. Students were then assessed on how their vehicle performed at the project showcase (35% of their project grade). Finally, the students needed to submit a final report (35% of their project grade) that summarized their project experience.

Table 1: List of Student Deliverables and Assessment Criteria

Assignment	**Weighted Assessment (Fall 2022/Fall 2023)**		
	Design	**Communication**	**Performance**
Research and Design Sketches	5%	5%	0%
Preliminary Design	14%	6%	0%
Progress Report	0%/0%	0%/10%	0%/0%
Testing Score	0%/0%	2%/2%	33%/28%
Final Report	22%/20%	13%/10%	0%/0%
Total (2022)	**41%**	**26%**	**33%**
Total (2023)	**39%**	**33%**	**28%**

A similar assessment structure was used for the Fall 2023 semester, with one modification. The students submitted preliminary design sketches (10% of grade) and a preliminary design report (20% of grade). Then, two weeks before the project showcase, the students completed a short survey (10% of grade) to inform the instructor of their progress on the project. This extra assignment was added to encourage students to start building their vehicles as early as possible. Students were then assessed on vehicle performance at the project showcase (30% of grade) and the final report (30% of grade). Across the assessments, students were graded on the quality of the designs, the quality of the written communication in the assignments, and the performance of their vehicle on testing day (every student that put forth significant effort to make a vehicle received full credit).

Results

Student reflections (as part of the project final report) and retention data are analyzed to understand how the project-based curriculum impacted student engagement in ENGR 1310 during the Fall 2022 and Fall 2023 semesters.

Student Self Reflections

The final section of the final report (completed at the end of the class) asked students to reflect on their experience with the project. Specifically, the students were given the following prompt:

Also, include a few remarks in this section about your experience with the project. Did you enjoy the project? Not enjoy the project? If you could do it again, what would you do differently? What advice would you give to next year's students if they were to do a similar (but not identical) project?

The same prompt was used for both years (2022 and 2023). The focus of these questions was student reflection, not project assessment; however, the student responses provide insight into how students interacted with the project. The analysis of student responses is limited to the first part of the prompt, addressing student enjoyment. The majority of students addressed the remaining parts of the prompt (regarding what they would do differently, advice for future students) by discussing time management or addressing flaws in their vehicle design. As an example, one representative student wrote:

"If I could do this project again, I would start designing and building the components on the 3D printer earlier than I did for this project. I would also troubleshoot all the parts I bought very early on to make sure they worked. This would allow me to only have to worry about assembling the robot vehicle. The advice I would give to next year's freshmen is to start early so that they will have extra time to make changes if any problems arise. Finally, the more preparation and research a person does on what works and what does not, the easier this project will be."

Comments like these are helpful for student reflection, and the advice from the Fall 2022 cohort was given to the Fall 2023 cohort before they started the project. Responses to the beginning prompt (about student enjoyment) gave greater insight into student perceptions of the project, so the remainder of this section will address those responses.

First, Table 2 shows how students addressed the question: "Did you enjoy the project? Not enjoy the project?". Each student's response was sorted into one of four categories:

- Student clearly indicated enjoying the project (label: Yes)
- Student stated they enjoyed the project, but also indicated difficulties/challenges that reduced enjoyment (label: Mixed)
- Student clearly indicated not enjoying the project (label: No)
- Student did not address enjoyment in their reflection (label: Didn't Answer)

Table 2. Student Enjoyment Responses in Student Reflections

Response Category	Fall 2022 (N = 30)	Fall 2023 (N = 42)	Total (N = 72)
Yes	21	30	51
Mixed (Yes, but…)	5	8	13
No	0	0	0
Didn't Answer	4	5	9

The majority of students (71%) stated they enjoyed the project. Several students indicated that the project was a feature activity of their semester. For example, here are quotations from three student reflections:

"This project was actually the highlight of my year and I actually enjoyed building and putting my mind to the task of completing it."

"The experience gained through this project was remarkable. It allowed the student to problem solve in a challenging way that most people probably have yet to experience"

"In the end, I would say that this was one of the most enjoyable projects I have done at the university. It aligned closely with my personal interests. The testing day was a great community experience as well."

Some students (18%) stated they enjoyed the project, but also indicated dissatisfaction with part of the project. For example, two students wrote:

"I did enjoy doing this project although it was very stressful and frustrating. I absolutely love coding it is one of my favorite things to do. … I do think that this robot being a very the first big project engineering and us being all freshmen and still trying to get used to everything was a little bit more stressful than I'm quite sure you planned on."

"I enjoyed the project when it worked. I had many struggles and setbacks while working on my project which added unwanted stress."

Some of these students may have had multi-faceted or conflicting thoughts about the project, while perhaps other students did not enjoy the project (but were afraid to write that viewpoint in their final report.) These feelings may also be a natural consequence of setting high expectations for student effort on this project. Nevertheless, most students stated they enjoyed the project while providing mostly positive comments.

The student responses were manually coded using an inductive methodology to identify key themes in their reflections. The manual coding involved three reviews of the student responses. The first review was to familiarize the authors with the student reflections and generate themes. The second review was used to apply codes to the responses, and the third review was used to confirm coding accuracy. Some responses contained multiple codes, while other responses contained no codes. Instances of the top seven themes that were identified during coding are shown in Table 3. No other themes were identified in more than three responses.

Table 3. Instance Counts for Themes in Student Reflections

Theme	Fall 2022 (N = 30)	Fall 2023 (N = 42)	Total (N = 72)
Fun	10	10	20
Challenging	7	11	18
Satisfaction/Accomplishment	7	8	15
Community	6	8	14
Design Experience/Iteration	5	8	13
Hands-On Experience	9	3	12
Stressful	2	7	9

When the faculty implemented the project in ENGR 1310, they had four goals in mind: the project should be challenging, open-ended, hands-on, and competitive. Three of these four themes were identified in the student reflections. Eighteen students discussed the challenging nature of the project (some with a positive tone, others with a neutral or negative tone.) Thirteen students mentioned enjoyment tied to the engineering design experience and/or making iterations on their vehicle, which directly ties to the open-ended nature of the project. Twelve students mentioned enjoyment with the hands-on nature of the project (using rapid-prototyping, using the Maker Space to build the vehicle, wiring the vehicle, programming the vehicle, etc.). Interestingly, only three students discussed the competitive nature of the project; however, anecdotal evidence from talking to students suggests that approximately 10 students were motivated to achieve the highest score in the class, while the remaining students were focused on completing their vehicle to meet the project objectives. Twenty students mentioned having fun with the project, which most likely has a strong correlation to the enjoyment students expressed about the project.

The inductive analysis revealed two interesting, positive themes from the project. First, fifteen students described a sense of accomplishment or satisfaction at completing the project. Secondly, fourteen students commented about the community and comradery they built with fellow students as they worked on the project. Some examples of these themes are shown in the quotations below:

"I would like to say that this project made me find a huge aspiration to become an engineer. I enjoyed the comradery, ambition and success of watching everyone, including myself complete the course."

"This project was amazing, I loved it and I think it was a very reasonable challenge for a freshman-level student. I liked working with people and helping them with little coding tips or having them help me with electrical [wiring]. Everyone had their own projects, but it was very much a group activity at times."

"This project taught me several things. ... Second, being able to ask for help from your peers makes you realize that everyone was in the same boat. Third, you need to be able to laugh off your mistakes. ... Lastly, this project was truly a lot of fun, especially when I had the "ah ha" moments."

The self-efficacy[11] and community[12,13] described by the students are both factors for engineering student satisfaction, so these themes were an encouraging result.

Another interesting result from the inductive analysis was the change in instance counts in the "Challenging" (7 to 11) and "Stressful" (2 to 7) themes between Fall 2022 and Fall 2023. On their own, these increases are not conclusive; however, anecdotal evidence (from communicating with and observing the students) also suggested that some of the Fall 2023 cohort struggled with the added complexity of picking up or pushing a bag of grain. These students were struggling to create a working vehicle, and any requirements beyond simple movement only made the project more stressful. These comments highlight a balance in the project: the project should be challenging and open-ended (allowing students room for creativity), while also accessible to students with a broad range of preparedness (allowing all students an opportunity to succeed with a high, reasonable level of effort). This balance will be readdressed before the course is offered again in Fall 2024.

Student Retention

As stated at the beginning of the paper, a major goal in switching ENGR 1310 to a project-focused curriculum was increasing engineering student retention. Specifically, the authors wanted to measure what (if any) effect ENGR 1310 had on a) first-year students choosing to continue in engineering and take the spring semester first year course (ENGR 1320) and b) whether these students progressed into second-year engineering courses. At UMHB, students are first classified as engineering majors once they are enrolled in Calculus; as a result, the majority of students in ENGR 1310 are not (technically) engineering majors. Practically, this means that retention rates for first year engineering need to be calculated by tracking the individual progress of each student who takes ENGR 1310.

Table 4 shows the retention rates of students enrolled in ENGR 1310 over the past six years. The data are calculated using the following procedure:

- Access the class roster for each section of ENGR 1310, starting in Fall 2018.
- Determine if/when each student enrolled in ENGR 1320.
- Determine if/when each student enrolled in a second-year engineering course – either ENGR 2320 (Engineering Mechanics: Statics) or ENGR 2330 (Electrical Circuit Theory).

Some students were removed from the population to focus on ENGR 1310 retention. For example: students who took ENGR 1320 before ENGR 1310 (usually students who transfer into the program for the Spring semester) were not counted. Students who took ENGR 1310 multiple times were counted the first time they enrolled in ENGR 1310, and not counted in subsequent semesters. Finally, students who took ENGR 1310 and are still progressing toward (but not yet enrolled in) ENGR 2320/2330 were included in the "ENGR 1310 to ENGR 2320/2330" data; the majority of these students took ENGR 1310 in Fall 2022, are still in good standing in the program, and will take ENGR 2320 or ENGR 2330 in Fall 2024.

In Table 4, the third column shows the percentage of ENGR 1310 students who went on to take ENGR 1320, and the fourth column shows the percentage of ENGR 1310 students who progressed to second-year engineering courses at UMHB. In the two years prior to the COVID-19 pandemic (2018-2019), the ENGR 1310-ENGR 1320 retention rate was close to 65%, and the ENGR 1310-ENGR 2320/2330 retention rate was between 40% and 45%. During the COVID-19 pandemic (2020-2021), both retention rates dropped, which led to the motivation for this work. The project-based curriculum was implemented in the Fall 2022 semester, and the ENGR 1310-1320 retention rate increased by 22% from 2021 to 2022. The ENGR 1310-ENGR 1320 retention rate remained above 60% for the second time the redesigned course was offered in Fall 2023. Another encouraging sign is the increased first-year to second-year retention rate (49% from the 2022 ENGR 1310 cohort, the highest from the past six years).

Table 4. Retention rates for students enrolled in ENGR 1310 and first-year students at UMHB

Year	ENGR 1310 Enrollment	ENGR 1310 to ENGR 1320 Retention Rate	ENGR 1310 to ENGR 2320/2330 Retention Rate	UMHB Fall-Spring Retention Rate	UMHB Fall-Fall Retention Rate
2018	56	66%	43%	86.3%	66.4%
2019	55	64%	40%	86.8%	69.4%
2020	28	46%	32%	82.7%	62.2%
2021	32	44%	34%	82.3%	64.5%
2022	33	66%	49%	87.1%	67.9%
2023	45	62%	---	83.6%	---

Although there is a strong correlation between the ENGR 1310 redesign and increased retention rates, there are other variables that could not be isolated in this study. One of the authors was tasked with (and implemented) the course redesign in Fall 2022, but three different instructors taught the course over the previous four years. Additionally, the effects of the COVID-19 pandemic on engineering enrollment are inherently linked with this result. Table 4 shows a slight decrease in retention rates across UMHB during the pandemic, but a much greater decrease among engineering students. The reasons for this discrepancy have not been fully established, but many factors (such as changing incoming student demographics and engineering-specific education challenges) could reasonably account for it. Because the redesigned ENGR 1310 course coincided with the tapering off of pandemic-related effects, these factors cannot be separated from the results shown in Table 4. Nevertheless, the increase in engineering retention rates in 2022 and 2023 are an encouraging marker that directly correlates to the ENGR 1310 course redesign.

Conclusions

The first-semester engineering course at UMHB (ENGR 1310: Introduction to Engineering) was redesigned to increase student engagement and retention in the engineering program. The curriculum centered around a single, individual design project. Students used the engineering design process to

design, build, and test a small robotic vehicle. Student self-reflections (submitted as part of their final report) revealed that most students enjoyed the project, and inductive analysis of the reflections identified common themes from student experiences:

- The project was *fun*.
- The project was *challenging*.
- Students experienced *satisfaction* or *accomplishment* by completing the project.
- The project built a sense of *community* through a shared experience.
- Students interacted with the full *engineering design process*, from ideation through testing, with many students performing multiple iterations as they completed the project.
- The project was *hands-on*.
- The project was *stressful.*

Finally, the course redesign correlates with an increase in first-year retention rates of engineering students. The retention rates of these cohorts will continue to be tracked over the coming years to determine if the redesigned ENGR 1310 curriculum affects student persistence over multiple years.

When the course is offered again in Fall 2024, the project will be modified slightly in two ways. First – as mentioned earlier in the paper, many students drastically changed their designs between the preliminary design phase and the testing phase. While iteration is part of the engineering design process, some students could have avoided design flaws with thorough research during the preliminary design phase. The preliminary design report assignment will be altered, encouraging students to add more detail to their designs before they order parts. Additionally, the project scope will continue to be adjusted to challenge the highest performing students, while also creating an environment where all students are encouraged to succeed.

The student reflections also point to areas for further study. One goal for future work is to examine how this project cultivates engineering identity[14] in the students. The "stressful" theme identified will also be examined in more detail in future semesters, to determine if this theme is specifically related to project expectations or is linked more generally to formation of an engineering identity[15].

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