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Experiences from a Cross Disciplinary Student Project: Biosensor Enclosure Design and Build

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Experiences from a Cross Disciplinary Student Project: Biosensor Enclosure Design and Build

Biology faculty at Francis Marion University (FMU) have need for an enclosure to contain, secure, and protect from the elements multiple internal and external environmental sensors, cameras, microphones, computational boards, and power supplies. Two enclosures are needed, one for terrestrial use and the other for aquatic applications. These enclosures are part of a larger project whose goal is to create an autonomous system of nodes to collect and wirelessly transmit microhabitat data to a central data repository for use in monitoring environmental conditions and overall biodiversity. This is a multi-disciplinary project involving students and faculty from the fields of Biology, Physics and Engineering, and Computer Science.

FMU has two undergraduate programs in engineering – Mechanical Engineering, and Industrial Engineering. These programs share several courses including Materials Engineering (ENGR220) and Manufacturing Processes (ENGR350). These two courses are offered once a year with the former being offered in the Spring and the latter in the Fall. In addition, ENGR220 is a prerequisite for ENGR350. This affords a unique opportunity to conduct two-semester design and build projects. This system was used in a collaborative effort by faculty in engineering and biology to design and build the biomonitoring enclosures. During the spring semester, in ENGR220, students were tasked with creating the geometric design and material specifications of the enclosure. In the fall semester, in ENGR350, students executed the designs from ENGR220 and constructed functional prototypes.

Prior to the start of ENGR220, both the ENGR220 instructor and biology professor were in contact to discuss engineering requirements, deliverables, and available resources (list of hardware internal and external electrical components). The discussions resulted in the development of a project description that included a problem statement, a list of must-haves, a list of nice-to-haves and a list of deliverables. This project structure was implemented twice – once during in 2022 and again in 2023. In the former, the project involved design of an enclosure for terrestrial biomonitoring, and the latter involved design of an aquatic biomonitoring enclosure. The goal of this paper is to report on the experience of conducting a two-semester multidisciplinary project which has design and build components.

In Spring 2021, students who were enrolled in ENGR220 were introduced to the terrestrial biomonitoring enclosure project during the last quarter of the semester. At the end of ENGR220, students provided a report that explained their enclosure's design and necessary material specifications.

In the following semester, in ENGR350, student teams were provided the reports from the ENGR220 class and asked to produce a functioning prototype. As many students were in ENGR220, student teams were reassinged to ensure that every student had new teammates. In addition, reports were assigned to teams such that every team received a report that was authored by students outside of that team. At the end of ENGR350, students built functional prototypes of the enclosures that were assigned to them, performed required testing, submitted a technical report, and presented their work as a business pitch.

In Spring 2022, students in ENGR220 were assigned a project to design an aquatic biomonitoring enclosure. In comparison to the terrestrial design, this project has unique challenges considering the environmental placement and incorporation of new aquatic sensors. The other difference was that student teams were not jumbled this time, and students were allowed to execute their own designs in ENGR350.

In terms of developing and executing such a project, the following factors need to be considered by faculty. The value of using open-source software and readily available hardware components is that cost for many items is minimal. The challenge comes when incorporating specific sensors such as the water quality sensors as they typically cost between $200 and $300. If true testing is to be performed, then multiple units of these sensors will be needed which can increase the cost significantly.

The multidisciplinary two-semester design-and-build project was successful in simulating multiple real-world scenarios. It allowed students to discover aspects of engineering that go well beyond a textbook. None of the logistical challenges identified are too big to solve. Such projects will continue to be implemented in the engineering curriculum at FMU.

1. Introduction/Background

Francis Marion University (FMU) is a liberal arts, Primarily Undergraduate Institution (PUI) with an enrollment of 3,752 (about 90% undergraduate students) as of Fall 2022. As of Fall 2021, about 40% of the undergraduate population belongs to racially minoritized groups, and 40% of the student body are first-generation college students (defined as students whose parents have not earned a degree from a four-year institution). FMU primarily serves the Pee Dee region of South Carolina, in which all but one county meets or exceeds the national average unemployment rate. FMU is classified as a Title III institution by the United States Department of Education, reflecting its predominantly low-income student body.

Engineering at FMU

Over the past ten years, FMU has introduced two Bachelor of Science (BS) degrees related to engineering. In 2013, a BS in Industrial Engineering (IE) was introduced, and this was followed by a BS in Mechanical Engineering (ME) in 2019. These degrees are designed to be broad in scope and include a manufacturing emphasis (due to regional industry needs).

The IE and ME curriculum share several engineering courses including an identical set of courses in the first three semesters. This allows students to explore both engineering fields before committing to one, and it also enables students to work in cross-disciplinary teams.

In the spring semester of their junior year, students take a three-credit hour Materials Engineering (MatE) course. This is followed by a four-credit hour Manufacturing Processes (ManP) course (with lab) in the junior year fall semester. Like all other engineering courses, these two courses are offered once a year causing students to move through the curriculum in consistent cohorts.

The structure of the curriculum and the two-semester sequence of MatE and ManP courses allows for unique student experiences to be designed. In the past, students have been tasked with designing a vacuum forming machine in MatE and building it in ManP. While this two-semester design-and-build project was effective, the customer for the vacuum forming machine was the course instructor. There remained an opportunity to improve the project by involving a customer who is external to the course. To capture this opportunity, engineering faculty collaborated with biology faculty to create two design-and-build projects for the two-semester course sequence.

Biology at FMU

The Biology Department at FMU provides students with a broad education allowing specialization in areas such as health care, ecology, and molecular biology. The department focuses on providing students opportunities provided outside of the classroom. For this reason, FMU in collaboration with both domestic and international partners have opened the Wildsumaco Biological Station (WBS) in Ecuador.

WBS offers students and faculty a destination for unique teaching and research projects. Many of the recent projects focus on identifying wildlife and recording environmental conditions in the surrounding areas. This work is done primarily using camera traps which are temporarily installed motion-activated cameras. We have identified, for instance, five cat species at Wildsumaco ranging in size from the small margay to the jaguar, the largest cat in the western hemisphere. In particular, data collected on the margay have revealed some of the highest densities of this elusive cat in the world. Yet, as a primary undergraduate institution, it is challenging to retrieve data from such a remote location.

For this reason, there is a need to develop an autonomous module capable of being installed in a rainforest that can record photos, video, sound and a suite of environmental data (air and soil temperature, light conditions, etc.), and transmit these data wirelessly to FMU. This has resulted in a truly cross-disciplinary project involving biology, physics, and computer science faculty and students, where computer science majors have contributed to software development, physics majors have helped configure and wire the internal functional components, and using two-semester design-and-build project, engineering majors have designed and tested the enclosure.

2. Benefits of a Design-and-Build Project

Design-and-build projects are employed by several faculty to provide students with problem-based learning opportunities. These projects afford students the opportunity to use engineering skills learned in the classroom, acquire new engineering skills based on the project, and hone their communication and teamwork skills [1]. These projects have most impact when the applications are highly practical and have a real customer [2].

From a more technical perspective, design-and-build projects require students to improve problem definition, develop and evaluate conceptual solutions, perform embodiment design, and finally construct/realize their design [2,3]. By doing so, students improve their spatial reasoning skills, recognition of cost of design decisions, and they realize the iterative nature of engineering design [2,4,5]. Researchers have noted that design-and-build projects are best conducted when they are for-credit. This creates an incentive structure that improves chances of sincere student participation, and it allows for instructors to enforce deadlines and expectations. Previous researchers have also employed a two-semester format for a design-and-build project [6].

Based on these findings, a two-semester design-and-build project was developed and implemented two times – once in 2022 and again in 2023. The project's structure, scope of work, deliverables, and resources are detailed in the next section. Student feedback and observations are noted in subsequent sections, and finally recommendations are noted.

3. Design of the Cross Disciplinary Project

This paper documents the development, execution, and experiences from a two-semester design-and-build project that was performed in collaboration with engineering and biology faculty. The project began when biology faculty approached engineering faculty with a need for an enclosure that would hold multiple sensors for biomonitoring. Both faculty discussed project scope, requirements, constraints, and deliverables prior to the beginning of MatE.

Broad scope of work: As a result of the discussions, it was decided that the project would be conducted in two parts. The first part would be in 2022 and would focus on an enclosure for terrestrial biomonitoring. The second part would be in 2023 and would focus on an enclosure for aquatic biomonitoring.

Resources: Sensors and other internal components to be placed inside the housing were provided by the biology faculty. Materials for prototyping and testing were resources from the Department of Physics and Engineering's MakerSpace. Students had access to a computer lab with SolidWorks© and were also given the option of using OnShape© for computer-aided design. Other requirements and constraints for each part of the project are listed in Table *1*.

Table 1: Problem Description and Requirements for the Project

Terrestrial Enclosure Project (2022)	Aquatic Enclosure Project (2023)
The Biology department at FMU have a need to monitor environmental data at two sites:	The Biology department at FMU have a need to monitor environmental data at two sites:

1. The Freshwater Ecology Center in Florence County 2. Wildsumaco Biological Station in Ecuador The metrics to be monitored are listed below: 1. Amount of rainfall 2. Wind speed 3. Humidity 4. Barometric pressure 5. Photo and video 6. Temperature 7. Luminosity 8. Sound Your team's goal is to design an enclosure that holds all the sensors required to gather data for the metrics listed above. In addition, your design must adhere to the following requirements: 1. Constraints (must-haves) a. Overall size is limited to 4in x 6in x 5in (not including necessary external units, i.e. microphones) b. The enclosure must hold the given solar panel c. The budget available to build the design is $150 d. The enclosure must be open-able to allow general maintenance to be performed, but sealed as to be submerged in water e. The enclosure must allow for an SD card to replaced with minimal effort f. The enclosure must have allow for cables to feed in and out of it without allowing water to enter inside g. The microphone for recording sound must be placed outside the enclosure h. The enclosure must disallow unauthorized access to the parts within i. The enclosure must be able to be secured at a specific location j. The enclosure must enable easy reconfiguration of sensors that it holds 2. Criteria (nice-to-haves) a. The camera position must be reconfigurable b. Minimize costDesign for service-ability	1. The Freshwater Ecology Center in Florence County 2. Wildsumaco Biological Station in Ecuador Specifically, aquatic environments have to be monitored for biological and environmental data. The components to be used and their purpose are listed below: 1. Computational board- Raspberry Pi Zero W 2. Interface for aquatic sensors- 4 port USB hub for Raspberry Pi 3. Camera module- NoIR (no infrared filter) camera V2 8 MP 4. Temperature, Barometric pressure, and humidity module- BME 280 sensor module 5. Luminosity sensor module- TSL 2561 6. Water quality sensors: a. Dissolved oxygen kit b. pH kit c. ORP kit d. Conductivity kit e. Temperature kit 7. Audio recording: a. AudioInjector hat for Raspberry Pi Zero W b. Circular connector Your team's goal is to design an enclosure that holds all the sensors required to gather data for the metrics listed above. In addition, your design must adhere to the following requirements: 1. Constraints (must-haves) a. Overall size is to be as small as possible (not including necessary external units, e.g., microphones) b. The prescribed design must cost no more than $100 (excluding sensors) c. The enclosure must be open-able to allow for limited maintenance on battery and the BME 280

	sensor, but sealed as to be submerged in water d. The enclosure must utilize multiple, water-tight circular connectors to allow for connection of external microphones and water sensors e. The enclosure must discourage unauthorized access to the parts within f. The enclosure must be able to be secured at a specific location g. The enclosure must enable easy reconfiguration of sensors that it holds h. Physical prototypes must be made 2. Criteria (nice-to-haves) a. Reduce conspicuousness b. Minimize cost

Structure: For the terrestrial housing enclosure design (first part of the project conducted in 2022), students were presented with the final project description and deliverables during the last quarter of the course MatE (Spring 2022). Students chose their teammates, and each team was limited to no more than three students.

At the beginning of Fall 2022 in ManP, student teams were changed. Every student was assigned to a team with members who were not from their MatE course. The enclosure designs (deliverable from MatE) were assigned to teams in a manner that every student got a design that was not theirs from MatE. At the end of Fall 2022, student teams presented their designs to a group of faculty members (including the biology faculty member) as a technical business pitch.

This structure was modified for the second part of the project in 2023 (aquatic housing enclosure). All changes are italicized. Students were assigned to random teams in MatE (Spring 2023) and *given the project during the second week of the semester.* In addition to this change, *physical prototypes and testing were made to be mandatory deliverables* at the end of Spring 2023. Students were also informed that *the same teams will be retained in Fall 2023 and that the* *students will continue to work on their Spring 2023 designs.* A summary of the structure of the project is shown in Figure *1*.

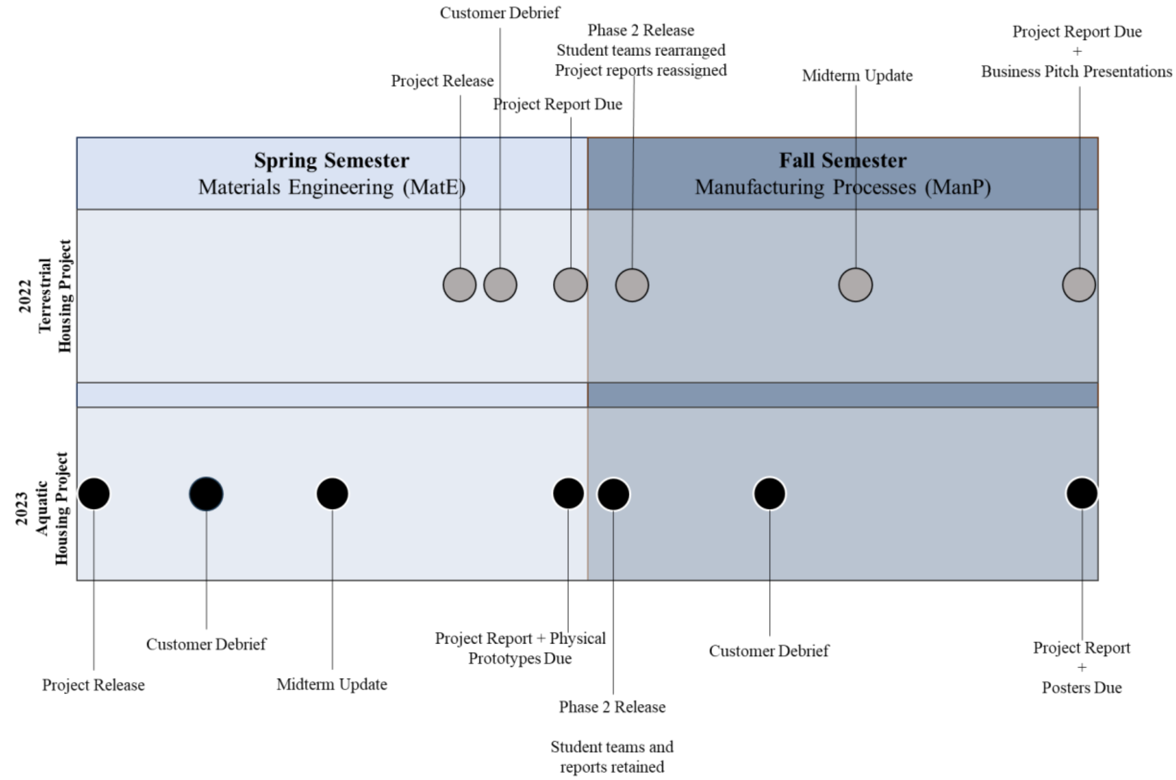

Figure 1: Structure of the project and its deployment in 2022, 2023

Time Investment: Critical to this project's success is the time investment from the biology faculty. The engineering faculty was the instructor of record for MatE and ManP. The biology faculty volunteered their time to meet with students during class sessions of both courses. They also had meetings and corresponded with students via email as requested by the latter. At the end of each part, the biology faculty also attended final presentations made by the students. This volunteered time investment was critical to achieve a key learning component of the course – students interacting with customers and eliciting requirements from them.

4. Observations and Feedback from 2022

At the end of each fall semester, students were asked to provide a one-page reflection that included likes, dislikes and learnings from the project. In general, the following themes and feedback were observed.

Hands-on experience: In general, students reported that they liked the hands-on, real-world application nature of the project. Students reported that they enjoyed discovering that their design decisions were feasible. For many students, this project served as their first experience with 3D printing for functional parts. They stated that this was beneficial especially since they had to ensure adherence to dimensions and tolerances. Students also reported that having a "real" customer whose practical needs would be fulfilled by the designs was valuable. The following quote from a student captures this sentiment.

> *"I also am really excited about the biology department actually putting our projects to use. It is always a great feeling to make something that serves a purpose."*

Engineering design: Students stated that they learned about the iterative nature of engineering design and to not be discouraged when designs fail and changes are required. In recognizing this, students also noted the importance of testing. The following quotes are from students in the 2022 iteration of the project.

> *"While doing the project I have learned that this project is a real representation of what happens in the field. The project represents what will probably happen to us as we first start are jobs that we will be given someone else's project and be asked to add on to the previous design without changing the overall look."*
> *"One of the biggest things I learned is that a product must go through various fails in order to succeed."*

Teamwork and communication: Students recognized the value of communication within and across teams. Students often experienced the need to find members of the team whose designs they were assigned in ManP. They needed this to gain information that may have been missing from the Spring 2023 reports, or to understand the intent behind design decisions made.

Students in 2022 disliked being assigned new teams and someone else's project at the start of ManP. They did acknowledge that this scenario is a good representation of real-world situations. Some students admitted that they were not "fans" of team-based projects, but over the course of two semesters grew to enjoy them.

Students noted that scheduling team meetings was often a challenge. Team-mates either had rigorous work schedules, incompatible class schedules, and/or were student-athletes. While challenging, some students used this as an opportunity to gain time management skills. Students were appreciative of extensive lab time that was offered for project work.

> *"While I wish I could have continued with my previous project from last year, I really enjoyed working with my new group members this semester. We all have unique individual skills which when put together work very well."*

> *"…through the trials of time constraints and stress it has made me personally become better at managing and balance multiple major projects going on at the same time."*

Faculty observed that students practiced with excitement for several hours prior to the business pitch presentations and this observation was supported by student feedback. Figures xxx show example designs generated by students.

> *"Also, even though some people did not enjoy having to present our projects, I thought it was pretty awesome being able to talk to people about this project we spent so much time on and present it to the man himself who is sending them out into the field."*

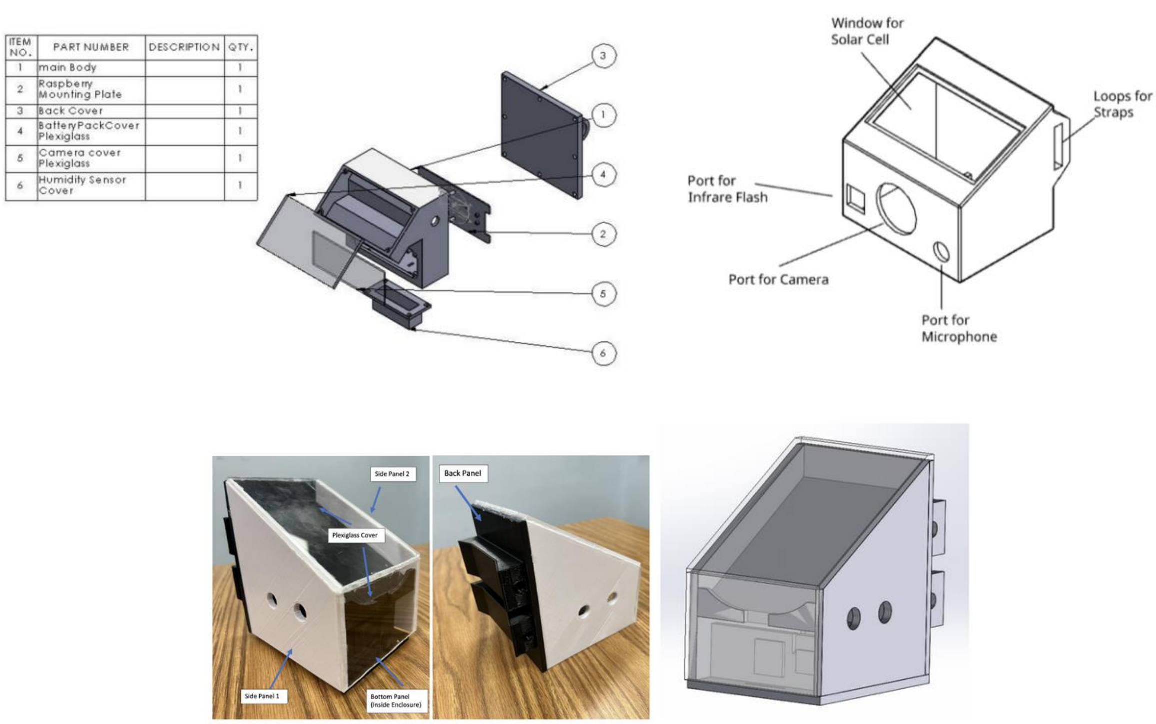

Figure 2: Example designs generated by students in 2022

5. Observations and Feedback from 2023

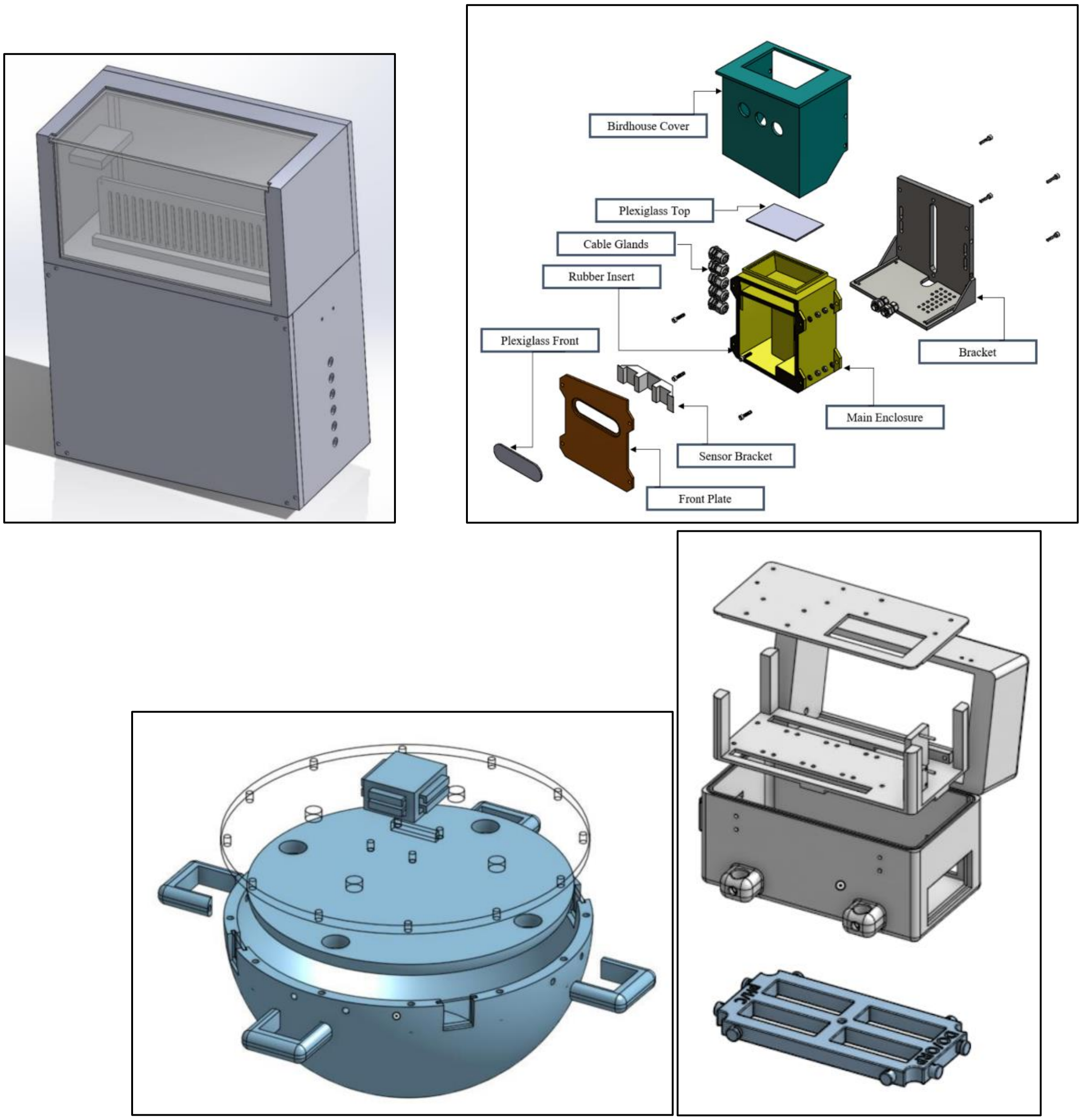

Figure 3: Example designs generated by students in 2023

At the time of writing this paper, fall 2023 is not complete. Formal student reflections will be collected at the end of the semester. However, the following anecdotal observations are noted:

- **Reliance on 3D printing:** Although students were encouraged to explore and use other manufacturing processes, almost all of them used FDM 3D printing extensively. While this was justified for some complex geometries, students were printing simple shapes such as circular plates.

Another logistical item that presented itself involved 3D printers. Although students were encouraged to use 3D printers sooner rather than later in ENGR350, many teams waited till the last few weeks of the semester. This resulted in a surge in demand for 3D printer time and with print times of some designs exceeding 20 hours, students realized that they may have erred.

- **Material specifications:** Students were encouraged to think deeply about material specifications from the perspective of functional requirements, cost constraints, and manufacturing limitations. Students rose to this challenge. A wide range of materials were used across all groups, ranging from HDPE to aluminum.
- **Purchasing of raw materials**: The Physics and Engineering department manages a MakerSpace where FDM raw materials are readily available and purchased on an as-needed basis. Teams that needed materials that were not available in the MakerSpace had to organize their needs with other teams and provide the instructor with a purchase proposal. The instructor took the proposal to their department chair who approved the purchases. This is a less-than-ideal approach as it would be preferred to secure funding at the start of the project.
- **Team members:** Some students did earn a passing grade in MatE and therefore were not able to take ManP in the subsequent semester. In addition, there were some students who were out of sync with the cohort and joined ManP after not being in MatE during the first stage of the project. It was a challenge for the instructor to ensure that teams affected with either situation were provided appropriate accommodations.
- **Prototyping v/s mass production:** It was observed that students struggled with differentiating between a manufacturing plan for a functional prototype versus a manufacturing plan for mass production. This might have been because students' knowledge of manufacturing processes grows during their time in ManP and they may be developing manufacturing plans without a full understanding of manufacturing.

6. Conclusions and Recommendations

This paper presented the design of a two-semester design-and-build interdisciplinary project. The project was conducted as part of a two-course sequence in an engineering curriculum. The second course in the sequence has a lab component and serves as the semester in which students realize/build the designs specified in the first semester. Various student feedback and instructor observations are noted.

Although there are challenges with implementation, a two-semester design-and-build project is beneficial for students. Some of these challenges are mitigated if the students move through the curriculum as a cohort. Another challenge can be addressed by providing course load incentive to the faculty member that plays the role of a customer. It is noted that having a "real" customer with practical needs for a product is a vital motivator for students.

Students may be more likely to explore manufacturing processes beyond 3D printing if they are given a quick summary of the capabilities available at their institution at the beginning of the project. This could also include providing students with the necessary training and certifications to use the tools available.

Students mentioned the existence of a final project from an Electronics course which is concurrently offered with ManP. A coordinated effort between ManP, Electronics and biology faculty could result in a project that is broader in scope and required technical expertise, but can be offered for credit by two courses.

7. References

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