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Integrating Engineering Design in Laboratory Sessions for Second-Year Mechanical Engineering Students

Dr. Deeksha Seth, Villanova University

Deeksha Seth is an Assistant Professor in the Mechanical Engineering department at Villanova University. Her primary research interests includes integrative and interdisciplinary engineering education.

Dr. Robert P. Loweth, Purdue University

Robert P. Loweth (he/him) is a Visiting Assistant Professor in the School of Engineering Education at Purdue University. His research explores how engineering students and practitioners engage stakeholders in their engineering projects, reflect on their social identities, and consider the broader societal contexts of their engineering work. The goals of his research are 1) to develop tools and pedagogies that support engineers in achieving the positive societal changes that they envision and 2) to address systems of oppression that exist within and are reproduced by engineering education and work environments. He earned his B.S. in Engineering Sciences from Yale University, with a double major in East Asian Studies, and earned his Ph.D. in Mechanical Engineering from the University of Michigan. He also holds a Graduate Certificate in Chinese and American Studies, jointly awarded by Johns Hopkins University and Nanjing University in China.

Prof. James C. O'Brien, Villanova University

Professor Jim Oâ€™Brien is a tenured Faculty member in the College of Engineering of Villanova University. At Villanova he has won numerous awards for teaching including the Lindback Award, the Farrell Award, and the Engineering Teacher of the Year Award.

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Abstract

Engineering design fosters students' capacity to apply technical knowledge towards innovative solutions. While design has gained visibility in engineering education through programs like entrepreneurship, freshman design, and senior capstone projects, there's a demand to integrate design across students' academic journey. The technical intensity of engineering curricula poses challenges in dedicating courses exclusively to design thinking or applying the design process. An alternative approach is to reimagine laboratory courses by incorporating engineering design. This pilot study explored the integration of engineering design principles in a required 14-week 'engineering analysis and design' laboratory course for second-year mechanical engineering students. The course combines lectures with hands-on laboratory sessions, covering topics such as gears, motors, dynamics, hydraulics, and engines. The course also introduces Ulrich and Eppinger's engineering design process and the ABET definition of engineering design to students, emphasizing open-ended problem-solving. The laboratory curriculum included two dissection labs, three Design-Build-Test (DBT) labs and a semester-long BeetleBot project, to provide practical exposure to mechanical engineering concepts. We sought to understand how engineering students drew connections between the lab content and engineering design. The course was assessed in Fall 2022 at the end of the semester through a voluntary, anonymous Google form survey that included questions about student impressions of the lab course. The survey recorded which labs were perceived by students as being most integrated with engineering design and which key aspects of engineering design (derived from the ABET definition) students felt were present in each lab. Results (n = 13) indicated that students perceived the BeetleBot project and DBT labs as the most integrated with engineering design, with the BeetleBot project being particularly well-regarded. Results suggested that engineering educators can leverage short-term DBT labs strategically to introduce design elements without the resource-intensive nature of semester-long projects. Despite the strengths, students felt that DBT labs lacked realistic constraints, suggesting an opportunity for improvement. Dissection labs received mixed feedback, indicating a need for intentional scaffolding to emphasize design aspects like creativity and iteration. Overall, the findings provide a foundation for future improvements and strategies for educators seeking to enhance design integration in engineering laboratory courses.

Keywords: engineering design; laboratory courses; product dissection; surveys; second-year engineering students

I. Introduction

A primary goal of engineering curricula is to train engineering students to design and develop sociotechnical solutions that meet societal needs [1]-[5]. This learning outcome is often addressed through senior-year capstone design courses and, increasingly, in first-year cornerstone design courses. However, research has described several knowledge gaps that students often possess at the beginning of their capstone courses, including lack of teamwork and project management skills [6], lack of experience with product development processes [6], and lack of experience with synthesizing stakeholder and contextual information into design requirements

[7],[8]. These gaps stem from a lack of consistent training in teamwork and design in engineering curricula prior to capstone [6] and negatively affect the educational mission of capstone courses to prepare engineering students for professional practice.

To address this gap, there is a pressing need to integrate engineering design content (including teamwork) throughout engineering students' academic journeys and particularly in their second and third years. The heavy focus on engineering science content within these two years has traditionally impeded efforts to deepen students' engagement with engineering design during these two years as well. For example, a common argument is that curricula cannot fit engineering design into second- and third-year engineering courses because doing so would require removing other important content. One solution to this dilemma is to opportunistically integrate engineering design into current courses with learning outcomes that are consistent with design content.

To this end, this pilot study investigated the extent to which second-year mechanical engineering students perceived engineering design as being part of core assignments within a 14-week mandatory 'engineering analysis and design' course. This course was a combination of lecture and laboratory components that provided students with practical exposure to foundational mechanical engineering topics such as gears, motors, dynamics (torque, speed, acceleration), hydraulics and engines. The laboratory component included five lab activities and a semester-long design project. Ulrich and Eppinger's Engineering Design Process [9] and the ABET definition of engineering design [5] were introduced to students in Week 2. Lab assignments and the semester project built upon introduced design content by encouraging open-ended problem solving. We sought to understand how students drew connections between course activities and engineering design to identify opportunities to deepen students' intentional engagement with engineering design. Our motivation for this study was to explore whether the existing labs effectively incorporated engineering design or required modifications. By examining the connections students naturally made in their engagement with course activities, we sought to evaluate the strengths of the current labs and identify potential areas for improvement.

II. Description of Laboratory Course

ME 2505: Analysis & Design is a combined lecture and lab course that is required for second-year mechanical engineering students at Villanova University. Students learn and apply technical knowledge through five labs and a semester-long design project. The lecture and lab are taught and led by faculty members in the department. Teaching assistants are present during the laboratory sessions to assist as students work in teams. Some version of the course has been taught at the University since 1998, and the original goal of the course was to provide mechanical engineering students with practical exposure to mechanical devices and manufacturing processes. Historically, lectures served as a "pre-lab" introduction that described the scientific principles underlying the mechanical processes that students were exploring that week. In 2018, aligned with recommendations from literature and national reports, the industry advisory board for the Department of Mechanical Engineering highlighted the importance of integrating engineering design in the curriculum to support the preparedness of the students. In 2019, the first author began updating the lecture content to include more intentional discussion of engineering design processes. However, the extent to which students were internalizing the new design focus of the course remained unclear, particularly since labs remained largely the same.

At the time of this study, lectures in ME2505 introduced students to the ABET definition of engineering design [5] and Ulrich and Eppinger's product development process [9]. Design content covered in lecture included stakeholder identification, needs assessment, translation of needs into engineering specifications, concept generation techniques like concept trees and combination tables, and concept selection using decision matrices. This overview, which aimed to equip students with foundational skills in engineering design, was completed in two weeks (i.e. four 75-minute sessions). For the rest of the semester, lectures introduced various methods to produce mechanical energy or do mechanical work, aligning with the lab content shown in Table 1. Each major theme concluded with one or more design-inspired problems or case studies.

Table 1. Summary of the lecture topics

Overall theme	**Specific topics**
Mechanical → Mechanical (Springs)	Conservation of energy Spring constants
Electrical → Mechanical (Motors & Gears)	Working principles and parts of DC motors Types of motors and gears Torque speed curves Design considerations when selecting a motor Gear ratios
Thermal → Mechanical (Engines)	Working principles and parts of an internal combustion engine Types of engines Metrics to design and evaluate engines
Fluids → Mechanical (Hydraulics)	Basic fluid principles Mathematical relations for hydraulic actuation

In the lab portion of the course, students engaged in three main types of design experiences: design-build-test labs, product dissection labs, and a semester-long design project. Each experience involved distinct learning goals and ways of engaging with mechanical devices and manufacturing. Course activities are summarized in Table 2. All three types of design experiences have been part of ME 2505 since close to the course's inception. Launcher Design and the two dissection labs were introduced in 2002, the Lego Car Race lab was introduced in 2004, and the current version of BeetleBot was introduced in 2006. The Hydraulic Robot Arm lab was introduced in 2022.

<u>Design-build-test labs</u>

Students completed three design-build-test labs: Launcher Design, Lego Car Race, and Hydraulic Robot Arm Design. In each of these labs, students used their knowledge of scientific principles to

Table 2. Summary of course activities

Lab Name	Type of Design Experience	Duration (weeks)	Design Goal
Launcher Design	Design-build-test lab	2	Launch a ball to hit a target that is between 3 meters and 20 meters from the launch site
Power tool dissection	Dissection Lab	1	Evaluate and redesign power tools that use gears, gear trains, and motors
Lego Car Race	Design-build-test lab	1	Accurately and reliably predict travel time of a constructed vehicle based on travel distance
Engine Dissection	Dissection Lab	2	Describe how engineering components function together to produce power
Hydraulic Robot Arm	Design-build-test lab	2	Pick up metal washers from a flat surface and put them into a plastic container
BeetleBot	Semester-long design project	4 weeks spread out between weeks 1-13	Multiple: Maximize short distance speed; maximize long distance speed; maximize maneuverability; maximize pushing force; destroy and defend from other BeetleBots

design devices that would effectively perform a specific task. Students were expected to evaluate their devices using the provided measurement equipment and implement performance improvements. Students were also expected to use required materials and design within given constraints. Design-build-test labs were completed by student teams over one to two weeks.

A. **Launcher**: The main learning goal of this lab was to apply the design process (establishing needs and specs, conceptualizing, prototyping, and testing) and learn about safely using basic assembly and manufacturing tools. In this lab, students designed, built, and tested a launcher (Figure 1) that launched a ball to a target within a desirable time. The ball, target and desirable launch time were given to the students. They were limited to using PVC pipes, rubber bands and basic hardware as their material. The students were introduced to basic manufacturing and assembly tools and safety procedures setting them up for the upcoming labs. Students also conduct kinematic analysis of the ball in flight and use conversation of energy principles to estimate the effective stiffness constant for their mechanisms.
B. **Lego Car**: The main learning goal of this lab was to understand the bridge between analysis and design decisions. In this lab, students built and raced cars using Legos, and utilized measurements, mathematical analysis, and statistical analysis to make their design decisions. The students were given a motor to begin their project. From there, students measured the no-load speed and stall torque of the given motor, designed a gear train (if they wish to do so), estimated the average linear speed of their designed cars, estimated the theoretical thrust that can be produced by their cars and measured the thrust produced by their cars. The students used various engineering principles related to motors, force, thrust, speed, and gear ratios to design their cars as well as measuring instruments like tachometers and force gauges to conduct their testing and analysis. At the conclusion of the lab, the students raced their cars.

The lab instructors assessed the speed of the designed cars as well as the accuracy of the predictions made by the students based on the analysis.

C. **Hydraulic Robotic Arm**: The main goal of this lab was to apply the design process (establishing needs and specs, conceptualizing, prototyping, and testing). The students designed, built, and tested a robotic arm that actuated using hydraulics (Figure 1). The students were informed that the designed robotic arm should be able to pick up metal washers from a flat surface and place them into a plastic container. They used syringes and plastic tubing to create the hydraulic actuation and used various materials like PVC tubing, wood, cardboard, and plexiglass for supporting structural material. At the end of the lab, student teams competed to see which robots can place the most washers into a plastic container in a specified time.

<u>Dissection labs</u>

Students completed two dissection labs over one to two weeks: Power Tool Dissection and Engine Dissection. In each of these labs, students deconstructed engineered products to learn how mechanical components are designed and interact. Students used their knowledge of scientific principles to analyze component performance and reflect on the potential design decisions that contributed to the final component designs. Students then reassembled the engineering products and, in the case of the Power Tool lab, suggested potential improvements.

A. **Product Dissection**: The goal of this lab was for students to identify the parts of a DC motor (e.g., armature, stator, commutator, brushes etc.), gears, and bearing, as well as understand how these mechanical components function in a product. The student teams disassembled, analyzed, and reassembled a hand drill, saber saw or handheld grinder (Figure 1). The students concluded the dissection lab by making recommendations about how the design of the equipment can be improved.
B. **Engine Dissection**: The goal of this lab was for students to identify the parts of an internal combustion engine and understand the purpose of each part and the functionality of the engine. In the lab, student teams disassembled, analyzed, and reassembled a single-stroke lawn mower engine (Figure 1). Students observed and took measurements while the engines were disassembled to answer questions about the venturi in the carburetor, valves, gears, valve timing, flywheel, magneto, ignition timing, bore, stroke, displacement, compression ratio, among other engine topics. Then the engines are reassembled and tested.

<u>Semester-long design project</u>

In the semester-long design project – **BeetleBot** – student teams had 13 weeks to design and build a remote-controlled vehicle that maximized performance according to several metrics. The design process for this project required students to synthesize knowledge learned during the semester. Students worked on their BeetleBots in class during four laboratory sessions spread out throughout the semester (weeks 1, 2, 6 and 10) as well as asynchronously outside the class as needed. There were no other labs during the four weeks allocated for the BeetleBot project. The BeetleBot project provided more advanced opportunities for students to use machining tools compared to the five labs. Students documented their design processes over the semester and received regular feedback on their processes from the instructional team. In week 14, at the end

Figure 1. Examples of lab activities during four of the labs. (A) Students testing their launchers designs, (B) Students testing the hydraulic robotic arm, (C) Students dissection a hand drill, (D) Students dissecting an engine.

of the semester, teams' BeetleBots competed in four skill competitions (short distance speed, long distance speed, maneuverability, and pushing force), as well as a battle competition where BeetleBots attempted to destroy other BeetleBots in one-on-one combat (Figure 2).

In the first meeting, students were given two DC motors, a remote control, and a receiver. They were also introduced to the arena where the final competition took place. Students then followed Ulrich and Eppinger's design process to identify needs and specifications for their robot, ideate different ways to design their robot, create multiple concepts for their robot and select the most promising concept. At the end of this process, students manufactured their robot, including the main chassis, storage for the electronics, wheels, motor mounts, gear trains (if needed) and any other component critical to the fabrication of their final robots. The week prior to the competition (which is held on a Saturday), the robots are tested and evaluated for strength (by pushing 1, 3 and 5 lb. weights), agility (by measuring acceleration and speed), and maneuverability (by going through an obstacle course). In addition, lab instructors also assessed the overall design and robustness of the robots. On the day of the competition, each robot competed in a double elimination competition (i.e., each robot had to be eliminated twice to be ruled out of the competition, giving students an opportunity to troubleshoot and repair robots after the first elimination). The arena, which is built with plexiglass had two lawn mower blades on two separate corners that spin at full speed for teams to use to damage competing robots.

The collaborative laboratory space for the course comprises of tables accommodating up to six students, with approximately six tables in the room where the lab meets each week. The space is equipped with measuring tools, sensors, and various hand tools such as screwdrivers, wrenches etc. Adjacent to this room is a state-of-the-art machine shop featuring an array of cutting, milling, metal bending, welding, and turning machines, including CNC machines for precision work. The collaborative space, project area, and machine shop are always accessible to students. The machine shop is stocked with materials like PVC pipes, aluminum sheets, bars, wood, and plenty of hardware, along with a variety of prototyping tools including 3D printers, rubber bands, and Legos. While shop technicians are available to assist with machining precision or complex parts, students have unrestricted access to the facilities. Each year, department funds allocated to the course are used to ensure students have access to all the material needed for the course activities.

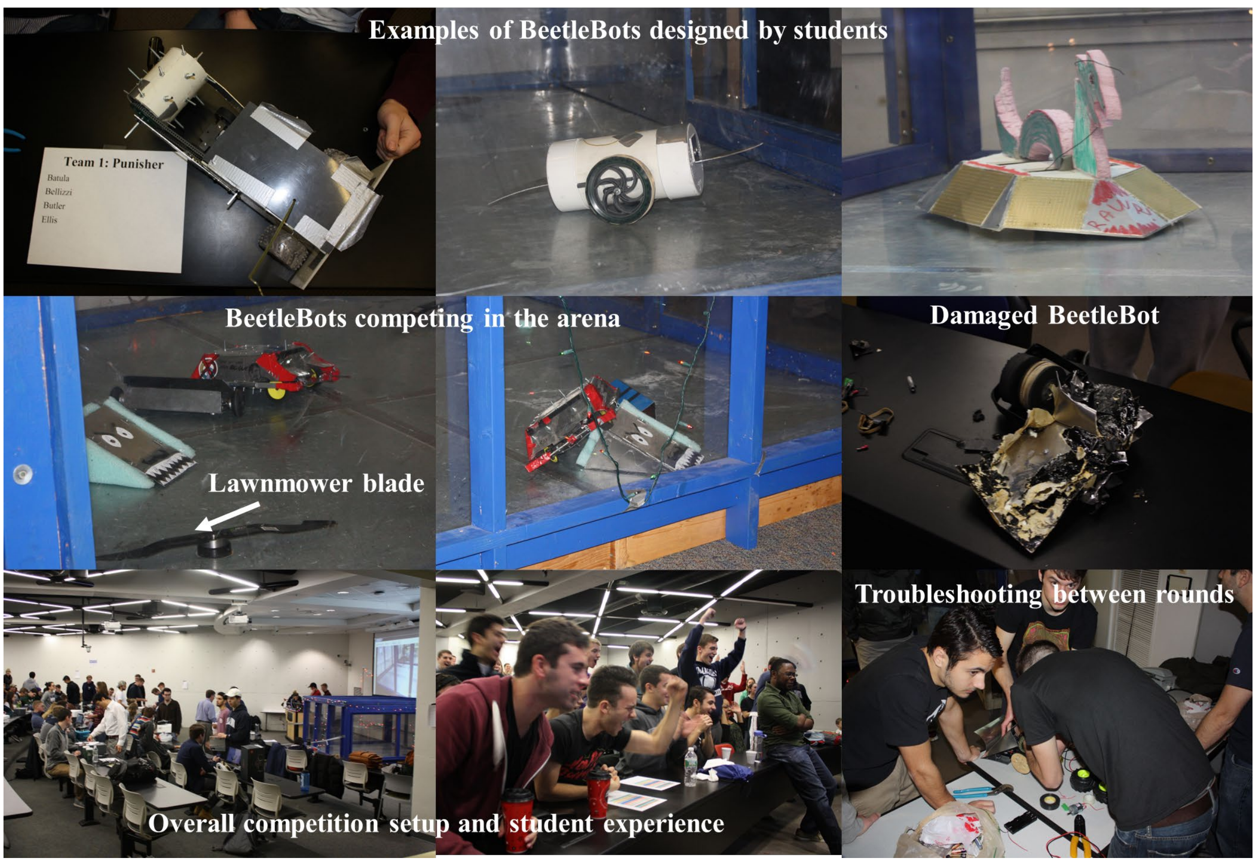

Figure 2. Examples of BeetleBots designed by students, competition round with three robots in the arena with the lawn mower blades, BeetleBot damaged when pushed into a spinning lawn mower blade by a competing robot, the overall competition room setup with students cheering for BeetleBots and students troubleshooting their damaged robot after the first elimination (in the double-elimination competition).

III. Methods

Research questions: We sought to understand how engineering students in ME 2505 drew connections between lab content and engineering design, for the purpose of potentially updating the lab content. Thus, this pilot study explored the following research questions:

RQ1: Which labs were perceived by students as being most integrated with engineering design?

RQ2: Which key aspects of engineering design did students feel were present in each lab?

Data collection: The course was assessed in Fall 2022 at the end of the semester. All students enrolled in the course were requested to complete a voluntary, anonymous Google form survey via email. There was no incentive to complete the survey. Thirteen out of seventy students submitted survey responses, for a response rate of 18%.

The survey included questions about student impressions of the lab course, along with a subset of three questions that were the focus of this study. These three questions are included below. These three questions were designed and implemented following recommended practices in survey design [10]. Specifically, they proceeded from most general (Question 1) to most specific (Question 3). In addition, the questions logically built upon each other and were directly relevant to the research questions that we sought to answer. Survey Questions 1 and 2 represented two different ways to answer RQ1, whereas Survey Question 3 directly addressed RQ2.

Respondents were presented with the following definition of engineering design, from ABET, during the survey. Students had seen this definition of engineering design in lecture during the second week of the semester.

"Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation. The engineering design component of a curriculum must include most of the following features: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statements and specification, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system description. Further it is essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics and social impact."

1. Share which of the following labs, according to you, was related to engineering design (limit: one choice)

Launcher	BeetleBot	Hydraulic Robotic Arm
Product Dissection	Engine Dissection	Lego Car Race

2. Share to what extent engineering design was integrated into each lab"
   Scale: not at all, somewhat, a little bit, mostly, a lot

Launcher	BeetleBot	Hydraulic Robotic Arm
Product Dissection	Engine Dissection	Lego Car Race

3. For this question, think about the following specific aspects of engineering design process and design education. Select respective labs where you felt you used the specific aspects of the engineering design process. You can select multiple labs if applicable.
   - is a process
   - meet desired need
   - iterative decision-making process
   - basic science, mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective
   - establishment of objectives and criteria
   - analysis
   - construction
   - testing and evaluation
   - development of student creativity
   - use of open-ended problems
   - formulation of design problem statements and specification
   - consideration of alternative solutions
   - include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics and social impact
   - the use of teams in problem solving

Data analysis: We recorded and aggregated student responses to our three survey questions. We used responses to Survey Questions 1 and 2 to answer RQ1, and responses to Survey Question 3 to answer RQ2.

IV. Results

RQ1: Which labs were perceived by students as being most integrated with engineering design?

The BeetleBot lab was most frequently selected by students in response to Survey Question 1, which asked students to choose a single lab that was related to engineering design. Nine out of 13 students selected the BeetleBot lab in response to this question, while three students selected the hydraulic robot arm lab, and one student selected the launcher lab.

Students also indicated that engineering design, according to the provided ABET definition, was highly integrated into the BeetleBot lab. In response to Survey Question 2, which asked students to rate how integrated engineering design was in each lab, 12 out of 13 students selected the highest Likert option ("A lot"). Among the remaining five labs, student ratings largely corresponded to the type of design experience. At least 9 out of 13 respondents (i.e., more than two-thirds) indicated that engineering design was either "A lot" or "Mostly" integrated into the

Design-Build-Test labs: Hydraulic Robot Arm, Launcher, and Lego Car race labs. In other words, respondents generally agreed that engineering design, according to the ABET definition, was integrated into these three labs. In comparison, at least 6 out of 13 respondents (i.e., just below half) indicated that engineering design was only "A little bit," "Somewhat" or "Not at all" integrated into the Product Dissection and Engine Dissection labs. In other words, respondents felt that engineering design was not as integrated into the two dissection labs. Table 3 and Figure 3 below summarize these results.

Table 3. Number of students reporting the extent of engineering design in each lab.

Lab	Not at all	Somewhat	A little bit	Mostly	A lot
BeetleBot	0	0	0	1	12
Launcher	0	0	2	6	5
Lego Car Race	0	1	3	4	5
Hydraulic Robotic Arm	0	0	1	5	7
Engine Dissection	1	2	3	6	1
Product Dissection	2	2	5	3	1

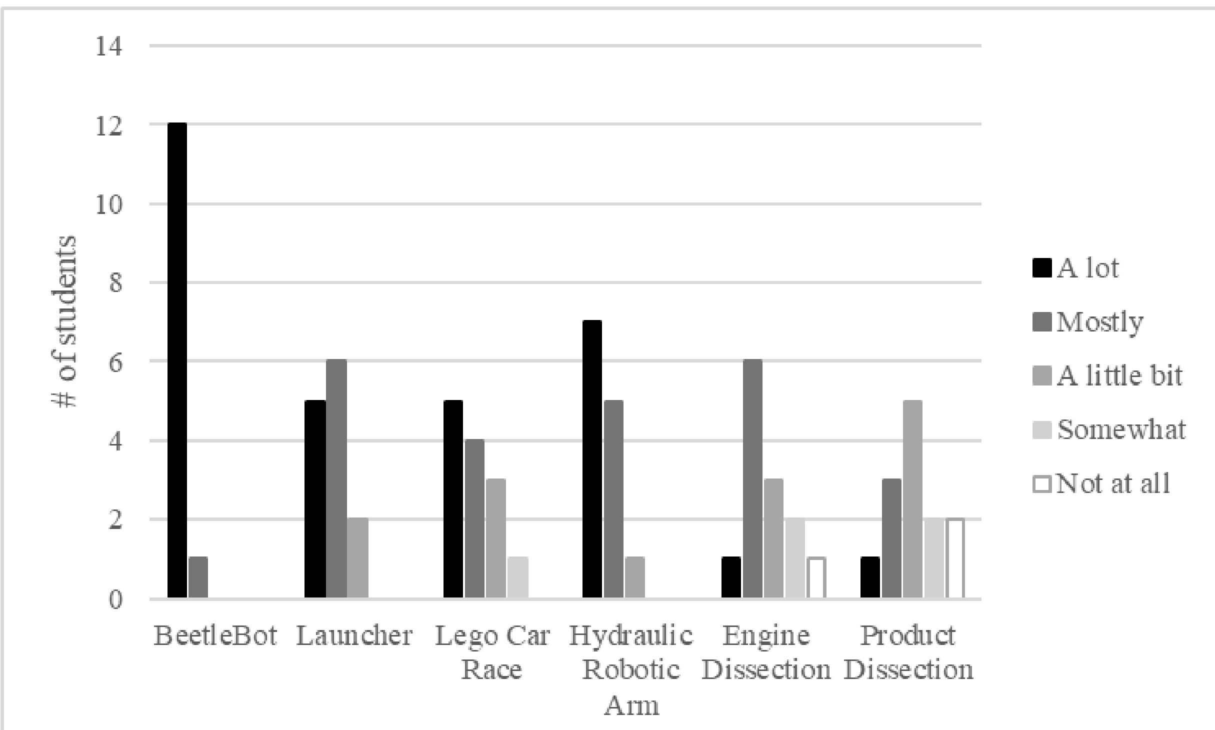

Figure 3. Number of students reporting the extent of engineering design in each lab

RQ2: Which key aspects of engineering design did students feel were present in each lab?

Survey Question 3 asked respondents to select aspects of engineering design from the ABET definition that they felt were used in each lab. We summarize our results for this question in Table 4. Aligning with our earlier findings, each aspect of engineering design was selected by at least 10 of 13 respondents as being used in the BeetleBot lab. The three Design-Build-Test labs also rated well across students, i.e., almost every aspect of design was selected by more than half of respondents as being present in these three labs. The exception (shown in Figure 4) was that only 5 out of 13 respondents felt that the Launcher and Lego car race labs "*include[d] a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact;*" this was the biggest difference in results between these two labs and BeetleBot. For the two dissection labs, few aspects of engineering design were consistently selected by respondents as being used in those labs. Out of the fourteen design aspects provided to students in our survey, only four were selected by 9 or more respondents as being used in the dissection labs. These aspects were "*is a process,*" "*establishment of objectives and criteria,*" "*analysis,*" and "*the use of teams in problem solving*."

Table 4. Number of students who perceived the presence of key components of the engineering design process in each lab.

Components of Engineering Design	BeetleBot	Launcher	Lego Car Race	Hydraulic arm	Engine dissection	Product dissection
is a process	11	11	9	10	11	10
meet desired need	11	12	12	13	5	3
iterative decision-making process	13	12	10	12	4	3
basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective	10	8	11	11	6	3
establishment of objectives and criteria	13	11	10	11	10	9
analysis	10	7	8	9	13	13
construction	13	13	10	12	9	5
testing and evaluation	13	12	11	11	3	0
development of student creativity	13	13	11	13	3	3
use of open-ended problems	13	12	10	11	3	2
formulation of design problem statements and specification	13	11	9	11	4	2
consideration of alternative solutions	13	10	11	11	2	1
include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact	12	5	5	8	3	2
the use of teams in solving problems	13	13	13	13	10	10

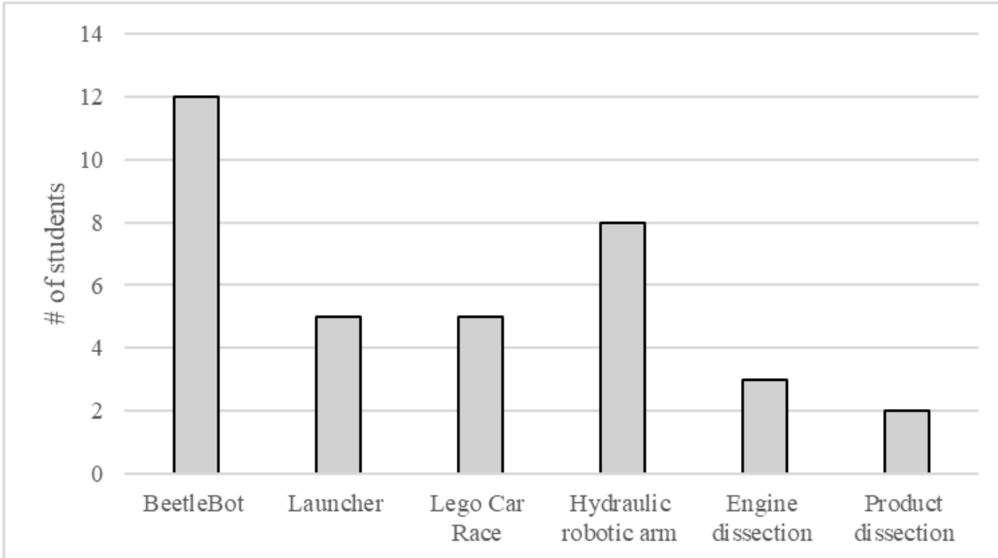

Figure 4. Number of students (out of 13 total) that indicated each lab "include[d] a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact"

V. Discussion

Student impressions of the integration of engineering design into the course laboratory activities

Students' responses to our specific aspects question (Survey Q3, RQ2) provided crucial context and depth for understanding how they ranked the degree of design integration within each lab (Survey Q1 and 2, RQ1).

BeetleBot emerged as the most integrated with engineering design in students' perspectives, as students consistently expressed that all aspects of design were well-incorporated into this lab. BeetleBot was intentionally developed to be a wholistic, open-ended design project that encompassed a full engineering design process. This lab was the most open-ended among the labs, allowed students to explore multiple solutions that met the given criteria, provided ample time for students to brainstorm and iterate on their designs, involved the fabrication of a multi-part robot from scratch, and gave students the most independence while working under clear constraints. The combination of these attributes likely contributed to the students' perception of BeetleBot as the most integrated design experience.

Students also recognized the integration of engineering design in the **Design-Build-Test (DBT)** labs. Respondents expressed the presence of all surveyed aspects of engineering design except one: realistic constraints. While the DBT labs involved components of manufacturing and open-ended problem solving, they operated within a more confined scope compared to BeetleBot. They also offered more structured guidance than BeetleBot, left less time for iteration, and operated with an analysis-driven focus rather than BeetleBot's synthesis-oriented focus. As an example, in the launcher lab, students designed a mechanism with PVC pipes and rubber bands to launch a ball from a given location to a marked target on the ground. The students had two lab sessions to design, build and test their solution. While the assignment description provided a simulated engineering context (launching emergency resources to a village after a natural disaster), this context provided flavoring but few practical design implications.

These differences between the BeetleBot and DBT labs could explain why respondents felt that the DBT labs lacked realistic constraints. The DBT labs included constraints, such as on materials and time for construction. However, our survey results suggest that respondents likely did not connect these in-lab constraints to broader engineering considerations such as social or economic factors. In theory, DBT-type labs can emphasize these broader factors, for instance by centering real-world social issues as the core context of the laboratory. Similar work has been done to integrate social content into other technical engineering courses such as thermodynamics [11] or control systems [12]. As these other examples illustrate though, laboratory assignments would need to be intentionally scaffolded to support students in making connections between technical engineering content and real-world engineering constraints.

Another way to interpret our results is that respondents recognized many of the same aspects of design in both their DBT labs and their BeetleBot project, despite the DBT labs being more structured, shorter-term, and more analysis driven. Other studies (e.g.,[13],[14]) suggest that the BeetleBot project likely provided several learning gains for students that were not reflected in our survey, for instance related to leadership, project management, and persevering through failure. However, our results suggest that short-term DBT labs could also be an effective way to introduce students to aspects of design such as meeting design needs, iterating on design ideas, and considering alternative solutions, without necessitating the large time and resource expenditures of full-semester design projects.

In contrast, respondents' perceptions of design integration in the **dissection** labs were mixed. Respondents indicated that relatively few aspects of design were involved in these labs. This result was surprising given that studies (e.g., [15]-[19]) have described product dissection as being effective for supporting engineering design. Our results likely reflect the specific characteristics of the dissection labs implemented in ME2505. These labs centered on identifying mechanical components and understanding the functioning of engines, rather than addressing broader questions about the purpose or rationale behind the product's assembly. The scope of these labs was limited to identifying component parts and their function with limited opportunity to iterate, evaluate against established needs or criteria, fabricate, formulate a design problem statement, think creatively, or consider constraints. By comparison, other examples of product dissection pedagogy (e.g., [20]) have embedded product dissection within lessons on idea generation specifically to support students' creative thinking. While the product dissection labs seemed to support respondents' engagement with technical analysis as it related to design, engagement with other aspects of design was limited.

Thinking across the labs as a whole, BeetleBot and the DBT labs seem to have introduced students in ME2505 to engineering design principles more effectively than the dissection labs. However, course context is also important; students were not completing the dissection labs in isolation but as one component in an overall course. In other words, it may not be necessary for the dissection labs to reflect an entire design process as long as they address limitations in the other labs. For example, the dissection labs seemed to provide opportunities for students to engage most deeply with technical engineering principles compared to other course assignments because students could analyze the function of real engineering components. This was the original intent of the labs: to impart specific technical knowledge rather than to foster open-ended problem-solving. Thus, while more could be done to emphasize the design decisions made by the engineers who created a given product (perhaps through the product analysis method described in Yilmaz et al. [21]), the product dissection labs contribute to meeting an important learning objective of ME2505 related to applying fundamental engineering science principles.

VI. Implications

Our study of student experiences in ME2505 suggests implications for other engineering instructors who would like to integrate design content into their labs or lecture courses.

1. Leveraging Short-Term Design-Built-Test (DBT) Labs:

Instructors can strategically integrate short-term Design-Build-Test labs as a valuable tool to introduce students to various aspects of engineering design within the context of technical courses. Our survey results suggest that even a relatively brief exposure to design elements in these labs can start to build students' understanding of design processes. In other words, resource-intensive semester long projects are not the only way to integrate design content into technical engineering curricula. Truly building students' skills as engineering designers would require more than a two-session DBT activity. However, brief exposure to design through short-term DBT activities could give students design touchpoints in their overall engineering curricula that enable them to better synthesize knowledge from their courses once they reach capstone.

In the context of ME2505, the three DBT labs can be further improved to include a variety of realistic constraints. To address this gap, future iterations of the three DBT labs could benefit from the incorporation of a broader spectrum of realistic constraints that mirror real-world scenarios. For instance, students could be tasked with optimizing their designs within a given budget, ensuring safety compliance, or considering ethical and social implications associated with their engineering solutions. By incorporating these additional dimensions of constraints, the DBT labs can more holistically expose students to engineering design.

2. Intentional Scaffolding of Dissection Labs for Design Emphasis:

For instructors that would like to use product dissection to teach design, our results suggest that intentional scaffolding is needed to support students in perceiving the design processes inherent to products. Our current product dissection labs support students' engineering analysis skills, but revision of these labs is needed to deepen students' engagement with design aspects like creativity and iteration. In addition to the product analysis method mentioned above [21], our dissection labs could also be revised to support student reflection on real-world design concerns.

For example, some requirements such as sustainability and realistic constraints like budget limitations, time schedule and resource availability can be shared prior to the dissection and students can reflect on how these pre-established requirements and constraints manifest during the dissection process. Students may reflect on the functionality and design choices in relation to the initial requirements, fostering a deeper understanding of the engineering decisions involved in creating products such as engines or power drills.

VII. Limitations

As a pilot study, this work is subject to several limitations. For example, we gathered only one type of data on student perspectives: survey responses. While our surveys explored students' perceptions of the labs from multiple directions, it is ultimately unclear *why* respondents felt that aspects of engineering design were (not) present in each course activity. Our response rate (18%) was also low compared to the overall enrollment in the course. It is difficult to predict how the remaining students would have responded to our survey. However, it seems unlikely that the overall trends that we observed in our results would change with more responses. Future work could include a comprehensive evaluation of ME2505 involving quantitative performance data, objective assessments, and qualitative feedback from both students and instructors to provide greater context to our initial findings.

VIII. Conclusion

The purpose of ME2505 was to introduce second-year mechanical engineering students to foundational mechanical engineering principles through engineering design-inspired lab activities. Formal instruction on engineering design processes was limited in the course, so we sought to understand the extent to which students connected current course activities to engineering design. Respondents viewed the semester-long BeetleBot project and the three short-term Design-Build-Test labs as being related to engineering design and as including many aspects of engineering design, although respondents also indicated that the Design-Build-Test labs lacked realistic constraints. Respondents did not relate dissection labs to engineering design as strongly, although all respondents felt that the dissection labs included analysis. Our results highlight current strengths of the course activities for introducing students to engineering design, as well as opportunities for improvement. In addition to informing potential iterations to ME2505 to deepen students' engagements with design content, our results also point towards potential ways that other engineering instructors could support engineering students' engagement with design in mid-curricula engineering sciences courses.

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