Structuring a Mechatronics Open Design Project to Reinforce Mechanical Engineering Concepts and Design Skills

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The objective of this paper is to share guidelines and lessons learned for an open design project in an Introduction to Mechatronics course. The open design project promoted project management, design skills, and hands-on experience in our mechanical engineering students. Historically, the undergraduate curriculum in mechanical engineering is front-loaded with lecture-style teachings in which the students are passive learners and note takers. The open design project prompted the students to explore their interests in mechanical engineering and to choose a project that challenged them to apply engineering concepts in a holistic manner. While the students were free to choose their topic, the projects were constrained to have an educational component. By doing so, they applied the newly acquired mechatronics skills, and built a device to teach prior engineering knowledge. During the semester, deliverables guided the students through a design process to solve the challenge effectively. Deliverables included: a project proposal, written reports, design reviews, early prototyping demonstrations, component integration, and a multimedia final presentation. Throughout the semester, students provided their opinions and suggested improvements for each deliverable. The contents of this work detail the different deliverables and the tools the students were given to help gain a foundation in mechatronics, design skills, and project management typical of senior capstone design projects. The paper also presents lessons learned and proposed directions for future improvements. To provide some specific examples of the projects and the main deliverables, a website[1] was developed with a sample of representative student work.

I. Introduction

The class *EML3811 Mechatronics I* is a required course taken by all mechanical engineering students during their Sophomore or Junior year at the FAMU-FSU College of Engineering and it is offered every semester. The class is delivered with a weekly 50 minutes lecture and a weekly lab of 2 hours and 45 minutes. For the labs, the class is divided into smaller sections of typically 20 students each and working in groups of 2. There is a main instructor for the class and lab with an additional teaching assistant (TA) for each lab section.

The semester-long class is divided into 2 main parts. The first half of the semester introduces students to C programming and the second half focuses on microcontroller programming, sensors, and actuators. Table 1 summarizes the topics covered in the class. Each laboratory contains a set of activities that students are expected to complete during the lab and a set of homework assignments.

1- https://ww2.eng.famu.fsu.edu/~camilor/Home/index.html

Table 1. Class Structure

Software Labs	
Lab 0	Introduction to the class
Lab 1	Standard input and output in C
Lab 2	Decision making (if statements, loops and case structures)
Lab 3	Functions and arrays
Lab 4	Pointers
Hardware Labs	
Lab 5	Breadboards, perfboards, and soldering
Lab 6	General purpose input and outputs
Lab 7	Motor drivers and DC motors
Lab 8	Stepper motors
Lab 9	Sensors and analog to digital conversion
Lab 10	Interrupts
Lab 11	Special topics

The designed lesson plans teach basic coding, embedded systems, and interfacing of sensors and actuators, which affords the mechanical engineering students a hands-on learning experience to code and design electro-mechanical devices. Furthermore, an open design project tasks the students to use cross curricular experiences in mechanical engineering to create a robust mechatronics design. The interdisciplinary nature shown in Fig.1 represents the synergy of mechanical design, electrical design, and coding.

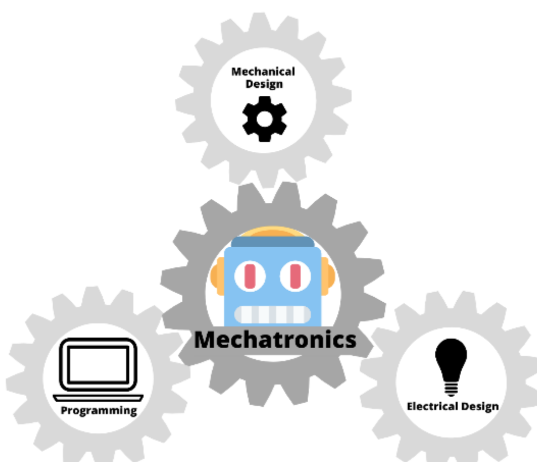

Figure 1. The objective of the course is to give undergraduate mechanical engineering students the ability to combine mechanical design, electrical design, and coding to achieve a multi-disciplinary project.

During the senior design class, students tend to focus their efforts in tasks such as geometric design, conceptual research, and project reporting, rather than creating early prototypes to guide the design process. In addition, the selected concepts are based on preferences and not necessarily what was best for the class or project objective [1]. Motivated by these observations, the open design project was structured into the activities detailed in this paper in Section II.

Previous work from Washington State University Vancouver (WSU Vancouver), University of Texas Pan American (UTPA), and Tri-State University (Trine) guided this paper's activities to increase cross curricular activities and improve upon foundational knowledge while developing a new skill set.

- WSU Vancouver recognized that students had little experience integrating multiple techniques required in design projects and used a two-tier project approach. In the first tier, students focused on simple projects that they were able to master and teach to their peers. In the second tier, students worked on more challenging projects that demanded knowledge of the techniques learned during the first tier [2].
- UTPA found a need for students to learn course work with more hands-on approach in supplement to lectures. This group used the introductory engineering course to allow students to create a tool that would be unique for different types of courses such as a tool for measuring forces and accelerations for dynamics-oriented courses or a device for measuring strains and stresses in materials in a mechanics of materials course [3].
- Trine focused on a course format that promoted completion of projects and presentations of results to improve the learning quality of the corresponding course work as well as to promote the presentation of technical skills. The first part of the course had a set of laboratory activities and the last 6-weeks required the completion of a project. During the final presentations, a faculty member was invited to observe the results of the students [4].

This paper seeks to help students learn in a project-oriented environment that will allow them to develop important skills to engineering, such as rapid prototyping, system integration, troubleshooting software and hardware, and time management. Using mechatronics as a medium, a vast array of work can be completed that is applicable to any discipline of mechanical engineering whether it be a small wind tunnel to observe fluid dynamics or a Charpy impact test to study material properties. By doing this, we promote cross curricular engagement and improve foundational knowledge.

In this work, we share guidelines and lessons learned for an open design project in an Introduction to Mechatronics course. The remainder of this paper is structured as follows: Section II details the requirements for the open design project and its deliverables. Section III includes lessons learned and avenues for future work.

II. Open Design Structure

In this class, open design is a project selected by the students but with the constraints of having an educational component. That is, the project can be used to teach a concept about other mechanical engineering areas. In addition, it has a set of minimum requirements described below to make sure that it qualifies as a mechatronic project.

A. Open Design requirements

All projects are completed in groups of two students to promote collaboration and interaction. The minimum hardware requirements include one actuator, two different sensors, LEDs, push buttons, and a form of display. In addition, the project must be a demonstration of a concept from any mechanical engineering field(s), such as statics, dynamics, thermal fluids, robotics, or materials. The Mechatronics lab provides the students with hardware to meet the minimum requirements. However, if the students wish to go beyond the minimum requirements, they must provide any specialized sensors or actuators.

B. Open Design Deliverables and Timeline

To facilitate progress and promote project management, the project is divided into five deliverables: project proposal, executive summary, mechanical prototyping, electronics and basic code functionality, and final presentation. These deliverables guide the students through the design process from conception to presentation in a manner that is educational and professional. More details of the deliverables are listed in Table 2.

Table 2: Deliverable Assignments for Open Design Project

Deliverable	Description	Completion Time [weeks]
Project Proposal	Students type a two-page report detailing a description of the project, how the requirements will be addressed, and a state diagram/flow chart of the proposed system.	1
Executive Summary	Each group prepares a two-slide executive summary presentation to be presented in class using the template of Fig. 2.	1
Mechanical Primitive Prototype	Using simple tools, such as cardboard, tape and glue, a primitive prototype is to be created to demonstrate a physical representation of the device and how the moving parts may move. Students are strongly encouraged to use this deliverable to go through multiple iterations of their initial design to improve the robustness and optimality of their design. The template of Fig. 3 is given to the students.	1
Electronics and Basic Code Functionality	Groups show all electronics involved in the project working according to the individual functionality of each component, i.e. motor motion, sensors' data acquisition, etc. These components do not need to be working with each other but must be able to demonstrate what they will do in the final device. Students must also submit a one-page report summarizing their milestones and plans to finalize their work.	1
Final Presentation	Students showcase their finished project. The device should look polished with clean housing and soldered wiring and connections. At this time, students turn in a final report and short video demonstration of their project.	2

The project proposal challenges students to create a project that fits the required criteria. They must also consider how their idea works, how it will be created and how long it will take for them to complete any and all necessary tasks. By completing this formal proposal, students are exposed to planning through a project of their own conception and adjusting their ideas according to feedback from the instructor and teaching assistants.

The executive summary seeks to encourage the students to produce high-quality summary slides of their concept as is typically required in an industrial setting. In addition, it aims to emphasize the linkages of the project to other fields within mechanical engineering. By presenting this summary to their class, they can incorporate the feedback and suggestions from their peers into their design. Figure 2 shows the template provided to the students for the slides.

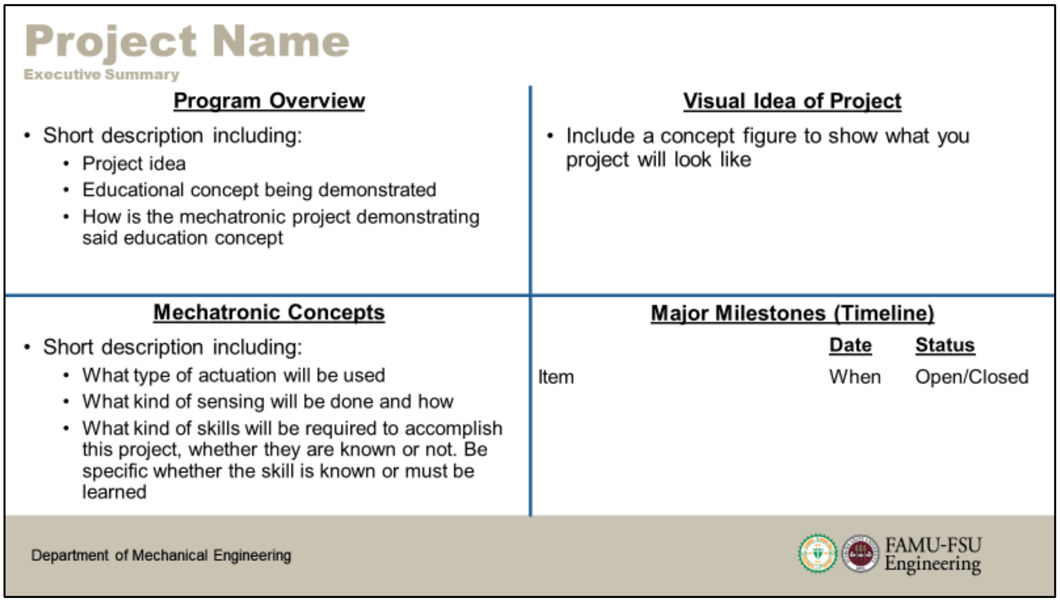

Figure 2:Executive summary template for open design project.

The mechanical primitive prototype encourages a habit of generating simple prototypes during the early stages of the design process. This deliverable tries to materialize their brainstorming sessions into fewer options and helps to identify potential issues and challenges in the project. By thoroughly iterating through multiple versions of their initial designs, students are given the opportunity to create the most robust version of their project concept. The prototype itself must be presented to the class using the template shown in Fig. 3.

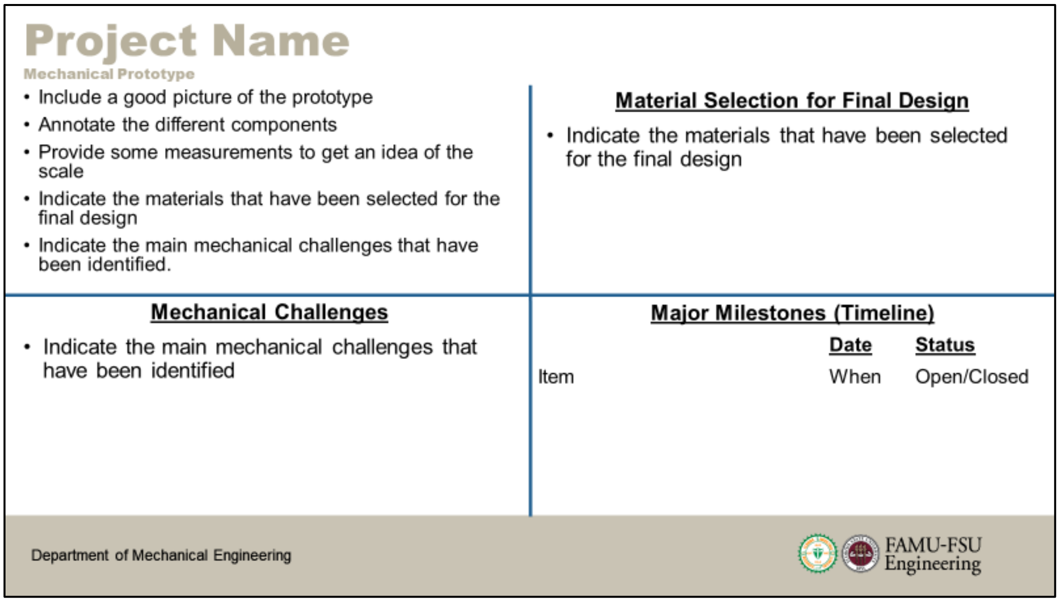

Figure 3: Mechanical prototype presentation template for open design project.

The electronics and basic code functionality deliverable tasks students to develop modular code so that they can debug potential problems at the later stages of the project. It also helps students learn the functionality of each individual component prior to integrating parts together. The one-page report gives students the opportunity to take note of their accomplishments and reflect on the remaining tasks.

Lastly, the final presentation deliverable includes several forms of showcasing their project. The main method is by demonstrating their final device working as initially proposed in the first deliverable. The second is by completing a full report explained in further detail in the next section. The third and final method is through a video that may be presented to a technical audience. These three different methods of presentation challenge groups to showcase their effort in a well-rounded manner. It is important for students to be able to publicly present their work and document it well for anyone to see.

C. Open Design Grading Rubric and Documentation Elements

The grade allocation of the open design is shown in Table 3. The evaluation forms are used as a method of obtaining feedback from students. This feedback seeks to improve the quality of the open design format and its deliverables. The documentation includes the following: a project overview where groups summarize what the project is, its motivation, and its application; a description of the algorithm or flow of the program including a state diagram or flow chart; operation instructions for the project as if a consumer were to use the device; a fully detailed wiring diagram using Fritzing [5] and source code. The final deliverable graded in the project is the final demonstration which the instructor and teaching assistants grade based on three different criteria: evaluation, complexity, and creativity. The evaluation portion of the grade determines how well the device works in all testing conditions. Students are given the opportunity to receive partial credit according to how functional their device is according to their proposal. The next criteria, complexity, determines whether students challenged themselves enough based on the material covered in class. Lastly, students are also tasked with conceiving a creative project design that is different from labs done throughout the semester. Students may receive extra credit according to how multidisciplinary their project is.

Table 3. Open Design Grade Allocation

Deliverables	Grade Distribution
Project Proposal Evaluation	5%
Project Prototype Evaluation	5%
Documentation	15%
Final Project Demonstration	
Evaluation	40%
Complexity	25%
Creativity	10%

D. Surveys

At the end of each deliverable, the students answered the survey in Table 4. The questions in the surveys are a combination of questions that allow the student to explain their design choices and provide opinions of each deliverable as it is completed. These answers are noted and used to gauge the progress of students. With their feedback, the guidelines for the open design project can be improved every semester.

Table 4. Survey Questions

Executive Summary Questionnaire	
Questions	
1	What did you not understand from the information presented on the executive summary slides?
2	What would you change to the executive slide?
Prototype Evaluation Questionnaire	
Questions	
1	How many different iterations of your design did you go through for this deliverable? e.g. an iteration would be a change from a 4-bar to a 5-bar linkage. Not a redesign of lengths.
2.a	After going through the prototype, what materials have been decided to use to build the project?
2.b	Why did you choose those materials (be honest)?
2.c	Is this the material you would use on a commercial application level?
3	How can prototype evaluation impact your final design?
4	After going through this process, what are the 3 main mechanical challenges that you foresee and how are you planning on overcoming them?
5	What would you change to improve this deliverable?

Electronics and Basic Code Functionality Questionnaire	
Questions	
1	What electronic components (sensor, actuator, etc.) did you test individually? Are they working as expected? If not, explain.
2	Which electronic component (sensor, actuator, etc.) has been the most challenging to work with? Explain.
3	What electronic components are you missing?
4	Why are you missing the components listed above?
5	Are the selected electronic components the ones you would use on a commercial application? Explain.
6	Do you have individual test code for the different components? Why do you think this is important?
7	What would you change to improve this deliverable?
Project Evaluation Questionnaire	
Questions	
1	What was the most challenging aspect of the project (programming, electronics, mechanical design, mechanical assembly, integration, etc)? Explain.
2	Did the project make you think about your engineering field in a more holistic manner? Explain.
3	Do you feel that by completing this project you gained a better understanding of non-mechatronics topics within mechanical engineering? Explain.
4	Rank the deliverables (executive summary, mechanical prototype, and code functionality) in the order of most to least helpful? Provide some reasoning for your ranking.
5	What would you do different next time that you face a similar design project?
6	Are there any topics that you feel should be covered in the future?
7	Is there a sensor, actuator, or any other resource (it could be a website, book, video, etc.) that you found useful? If so, please comment on it so future students can benefit from it.
8	Do you have a final video of your main achievements? If so, are you proud of it and would you feel comfortable showing it to a potential employer?
9	Did you reinforce any design skills (e.g., CAD, mechanism design, structural design, motor selection, etc.) by completing this project?
10	Did you reinforce any analytical skill from other mechanical engineering classes?
11	What educational concept does your project demonstrate?
12	What previous classes from the ME curriculum did you find useful and why?
13	Were you able to adhere to your timeline? If not, what changes would you have made?
14	What would you change to the open design requirement to improve the experience of future students?

III. Lessons Learned and Future Improvements

This section presents lessons and perceptions from the authors based on the different deliverables and the final project demonstrations.

A. Executive Summary

The overall response of students to the executive summary was positive. They appreciated that it encouraged them to think about their project for the entirety of the semester. However, the students pointed out that there may have been a bit of unclarity for the purpose of some of the quadrants in the executive summary. As an audience, some students had issues interpreting how a team would go about working towards their goal and what the milestones generally meant. The deliverable had a positive influence on the students, but with some improvement on details of what is to be done, it could be more beneficial.

B. Mechanical Prototype

The mechanical prototype deliverable was well received by the students and was found to be a key element to help guide the design process. A vast majority of students found the prototyping very helpful and that it contributed towards the creative process and to clearly identify potential issues. The average number of iterations was approximately 3. In most cases, the different iterations corrected issues with sizing, general shape of the structure, interference between mechanical parts, and placement of sensors and displays. In several occasions the new prototypes were generated because students realized that the original idea was too complex to achieve in the limited time.

Most students selected wood and 3D printed parts to prototype. The main reasons are the materials are inexpensive and easy to work with. However, the course instructor found that due to the proliferation of 3D printing, many students are skipping a proper material selection process for their designs. A proper material selection process should be included in future iterations of this class.

Through the prototyping stage, the students were able to identify the main mechanical challenges, which often tend to be related to friction, actuator sizing, and specification of mechanical components. However, many of these issues were not solved in their final deliverable. An early plan to account for this should be devised in the future.

C. Electronics Code and Functionality

For this deliverable, most groups had all of their equipment needed for their project. The few that did not, had either ordered late or ordered new equipment that they had not planned on originally ordering. A good number of groups did find difficulty in getting certain things to work; however, all of these parts were things not specifically taught in class and students had to apply themselves to learn how to get these components working. The overall response to this deliverable was well taken, especially when prompted with having testing code for individual parts. All groups learned that integration was a challenging part in cross-disciplinary projects and having specialized code to test the functionality of individual parts was essential to debugging and troubleshooting.

D. Final Survey

At the end of the semester, students were asked in a final survey questions about their experience throughout the project. In general, the students reported that the number of topics covered in the class was considered sufficient for them to work on the projects; however, they faced issues with integration and coding. They found it difficult to perform full integration of their components within the two-week time frame. Perhaps, they were not aware of the issues that may arise from integration and this lesson could be emphasized by bringing industry experiences into the classroom.

Overall, by completing this project, students seemed to get a better appreciation for the engineering field. It was observed that most projects utilized concepts from dynamics and mechanical design, which was expected. To promote more variety in projects, examples of concepts in different mechanical engineering disciplines could be shown during the assignment of the project. These examples could be created with the aid of other professors in the department. By reaching out to other professors, it allows students to better connect their project with work from other classes.

According to student responses, informing them of time management and giving them access to useful resources would be most beneficial for productivity. Whether students found tasks to be more challenging than expected or did not account for delays to happen, time management was the key issue that students expressed wanting to improve. In addition to better informing students of how time-consuming certain portions of the design process may be, a collection of useful resources can be compiled and be made available on the class website.

D. Survey Responses

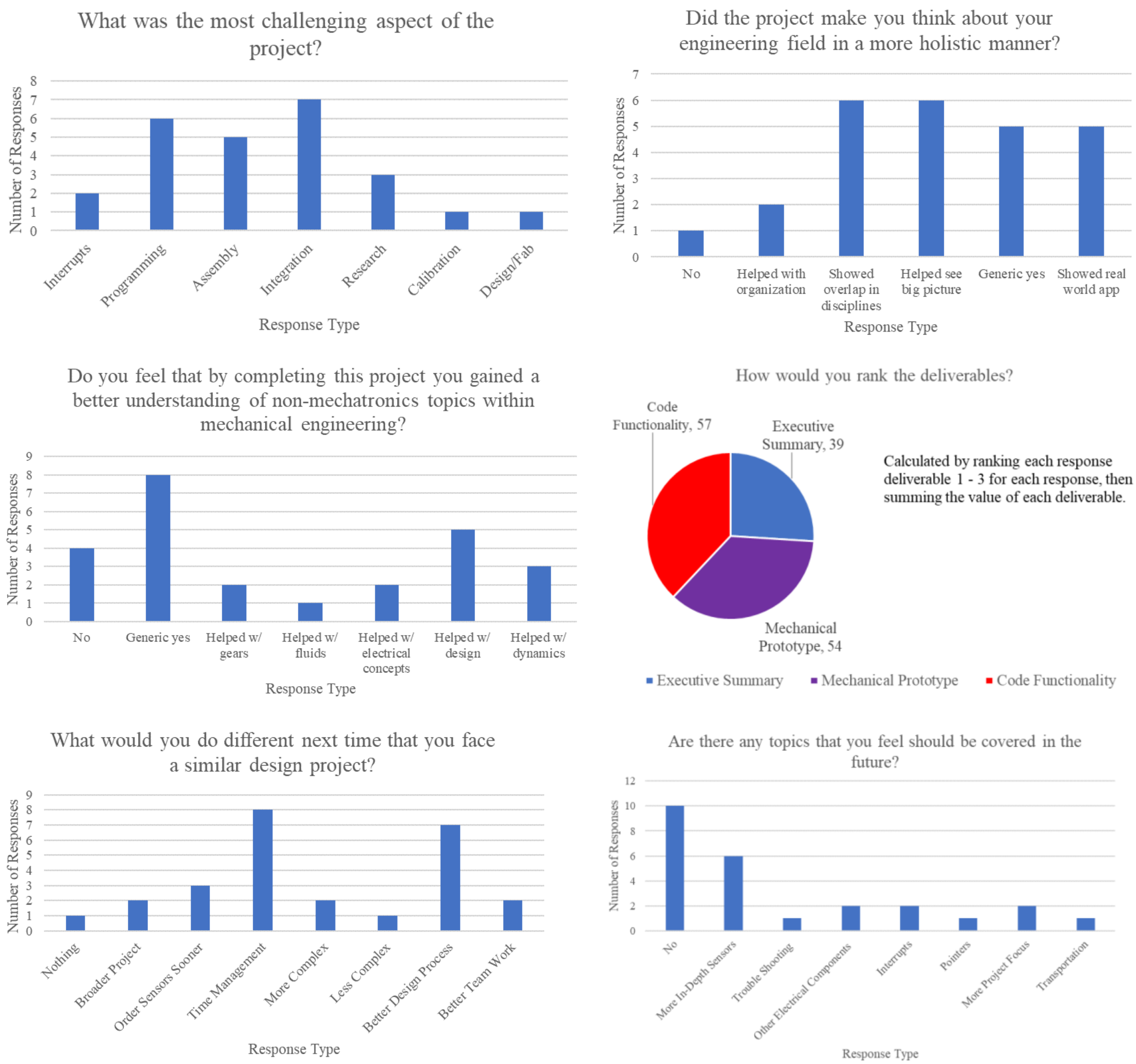

Figure 4:Responses to questions 1-6 of final survey.

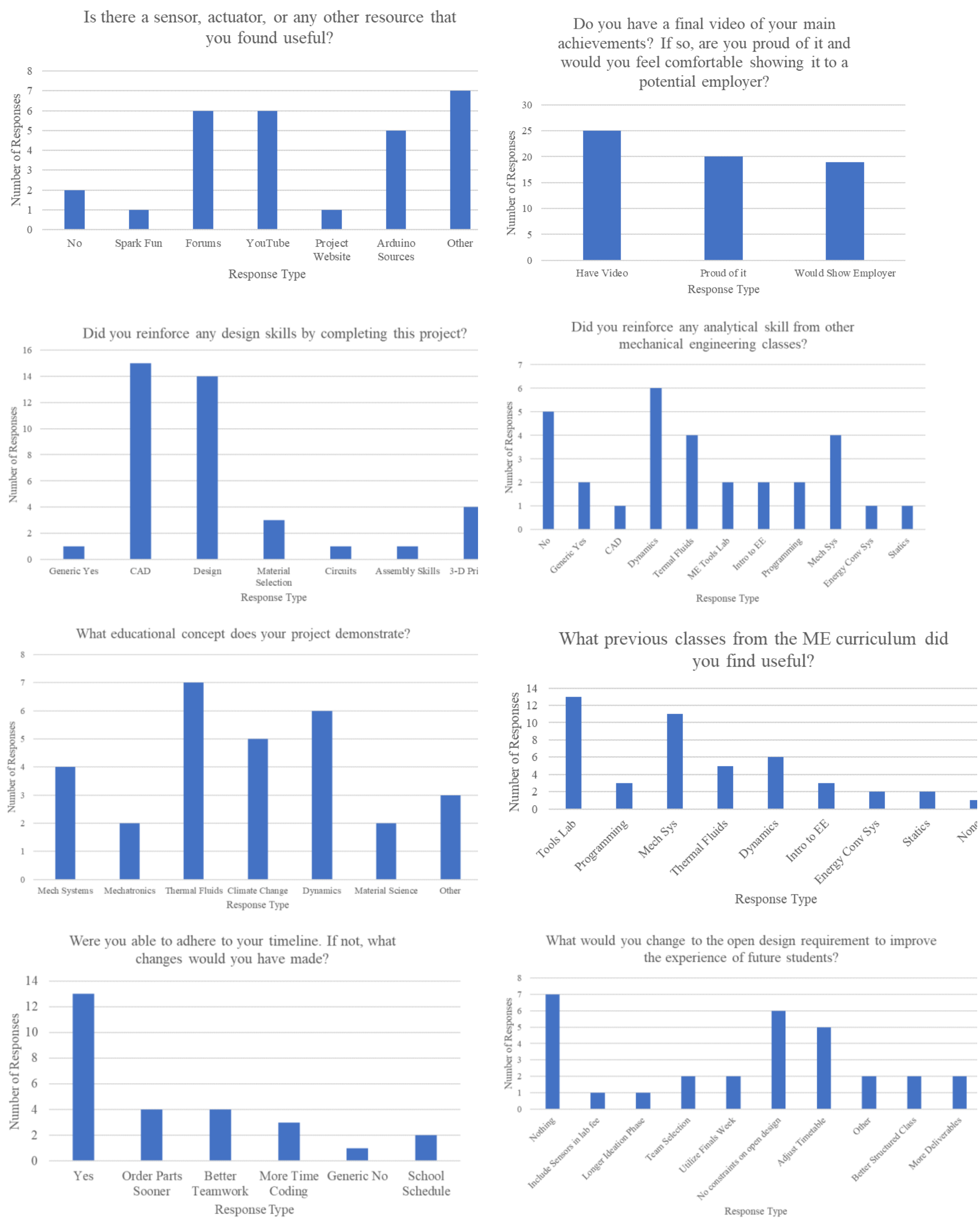

Figure 5:Responses to questions 7-14 of final survey.

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