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Engineering Education via Solar Car Design: A Case Study

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ENGINEERING EDUCATION VIA SOLAR CAR DESIGN: A CASE STUDY

ABSTRACT

Design projects are crucial to engineering education and the learning process, as they expose students to real-world projects. They allow for academic knowledge to be applied in specialized environments, while also providing an opportunity to gain new skills and knowledge. At Florida Polytechnic University, a science, technology, engineering, and math (STEM) driven university in the southeast region of the United States, The Phoenix Racing Solar Car team is a prominent example of one of these opportunities. The Solar Car team is the first interdisciplinary, large-scale build, competition team on campus.

The team works to design and develop the most reliable and efficient solar-powered racing vehicle to compete in the American Solar Challenge (ASC) Formula Sun Grand Prix (FSGP), representing the university on the international-collegiate level. The focus of the competition is to design, build and test a vehicle that relies off the conversion of energy from the Sun to both power the electric motor and to charge the battery pack to drive long distances on green energy.

To examine the educational and professional value of this experience for students, the members were surveyed about their experience at their first-ever competition during the Summer of 2024. This survey was focused on better understanding the benefits of the design project that they were a part of. They reported relevant prior experiences, their contributions, skills earned, and their personal and professional growth. Results from this survey showed that students had significant advancement in knowledge and skills, by contributing to this project, primarily in different design and manufacturing methods. Additional information supporting the benefit of such projects is derived from reported student experiences and positive impacts from their personal experiential gains.

Keywords: Engineering Education, Design Projects, Solar Car Racing, Design and Manufacturing Skills, Interdisciplinary Teams

1. BACKGROUND

Design projects serve as an opportunity for students to apply theoretical knowledge in hands-on challenges, often across disciplines to enhance collaborative efforts and skills [1], [2]. Design projects in undergraduate STEM education can exist throughout the curriculum, in a specific design course, or as an extracurricular activity. Design projects can simulate real-world experiences to increase students' technical and professional growth.

1.1. Design Projects in STEM Education

Undergraduate STEM education is developed to teach and prepare students for upcoming industry challenges through the development of skills and knowledge [1]. Students are given the opportunity to address different types of challenges throughout their learning experiences. One of the challenges that students may face exists in the form of design projects. Design projects teach students how to apply the theoretical knowledge that they have obtained throughout their curriculum to practical applications. The application of design projects has increased in the curriculum with the rise in the popularity of Problem-Based Learning (PBL), which helps give students a basis or set of steps to begin their work toward a solution [2]. Students must utilize their critical thinking skills and serve as independent learners to satisfactorily complete the project [3]. These projects not only bridge theory to application but also allow for the opportunity to experience real-world challenges, where students are allowed to be creative and innovative. Frequently, design projects in STEM fields are interdisciplinary, with students from multiple majors collaborating. In addition to collaboration with others, it allows students to integrate their knowledge and ultimately stay more motivated and engaged in their future careers [4]. A primary skill taught to students while working on design projects of this nature is team collaboration, which comes from the simulation of real-world experiences, preparing them for their future [5].

1.2. Design-Build Competitions in STEM Education

University-level design-build competitions exist internationally, to get more students involved and engaged in STEM. Typically, these competitions involve hands-on experience, like Innovation Competitions and Programs (ICP) do. Hands-on experiences are important to the growth of students because this is where they will have the opportunity to develop technical and professional skills needed for industry [6]. Students who are given the opportunity to participate in a competitive environment such as this are provided with the most authentic experience of real-world problem solving, where they will see how to balance work with a team and maintain structure, in addition to the promotion of innovation and creativity [7]. Involvement in these projects can help bolster a student's skills, advancing their understanding beyond the extents of the classroom. Design-build projects typically happen outside of the classroom environment, allowing students to build lifelong learning skills [8]. Aside from skills learned and critical thinking, design-build competitions in STEM education are meant to excite students, allowing them to feel pride in the work they put forward [9].

1.3. Solar Car Racing in STEM Education

There are a wide variety of design-build competition projects available at the university level. One example of such projects is solar car racing, a niche topic area combining automotive and renewable energy sources to create a unique engineering challenge for students. The Formula Sun Grand Prix (FSGP) and the American Solar Challenge (ASC) are just a few of many competitions held around the world that houses this type of racing [10]. One of the original races, the '95 Sunrayce, started the popularity of this event. Sunrayce began as a senior capstone design project, with the goal of expanding to give more students the opportunity to participate. This allows them to develop skills to design, build, and race a vehicle powered by solar energy [11]. From learning technical or soft skills to problem-solving skills, students find the experience rewarding and to be worth expanding further into their curriculum [12].

1.4. STEM Education Retention

Though there are many curricular and extra-curricular opportunities available to STEM students, the content or curriculum is structured to be rigorous and challenging. Due to this, the challenge of student retention becomes apparent. Students may decide to leave the STEM fields to alleviate the stress due to rigor. However, educators also see it as an opportunity to teach students how to persevere and prevent this from occurring. One method that has been shown to reduce student attrition within STEM disciplines is to provide these hands-on experiences, such as design-based or team-based projects [13]. Successful implementation of these projects requires thoughtful structuring and management. For example, the Blue Devil Motor Sports club uses this approach by establishing a sustainable organizational structure for their design projects. Their structure tasks upperclassmen with mentoring and educating the underclassmen, to help avoid the loss of knowledge or team function [14]. This also fosters a sense of belonging in the underclassmen, strengthening team cohesion and commitment.

2. METHODS

This study seeks to examine the student benefit of participating in a multidisciplinary design-build project. It focuses on engineering students who participated in a year-long solar car racing competition team. The students completed a post-competition survey that was a mix of Likert scaled and open-ended questions to gather information on their experience, contributions, demographics, and takeaways from the project experience. The data was analyzed by identifying trends in the qualitative data and summarization of the quantitative data.

2.1. Participants

The subjects of this study are the small group of students from Florida Polytechnic University's Phoenix Racing team. This group of students were participants at the FSGP solar car race in Bowling Green, Kentucky. This was the team's first appearance in this race, as well as the first "big build" competition team at the university. In this instance, the term "big build" refers to a large format project in which students are tasked with designing, building, and testing a project with significant focus on innovation. The development of a solar car requires a wide range of expertise, encompassing all STEM fields. Among the degree programs offered at the university, students participating in the recent solar car competition were either mechanical engineering, electrical engineering, or engineering physics majors. While the Phoenix Racing Solar Car Team is open to students from all academic disciplines, these three programs were the ones represented during the competition. This team also had students with a variety of other backgrounds, synonymous with a professional engineering environment, allowing students to engage and develop skills in design, manufacturing, systems integration, and project management.

2.2. Survey

The survey was disseminated to the students who participated in the FSGP solar car competition in Bowling Green, Kentucky. It was given to the students one week after returning to the university from the competition, in July 2024. Students self-reported information by reflecting on themselves and their personal experiences. This includes their experience at the competition and while on the team, such as how they thought the competition went, how they felt the team did, their contributions, and how to improve the team. Students also report their demographics (degree and grade level) and any relevant experience learned while on the team; relevant experience can include personal growth, skills, or techniques for the continuation of the team. The survey consisted of a mix of open-ended and multiple-choice questions, where students make their personal remarks of the experience of learning and development whilst on the project.

2.3. Analysis

The self-reported survey responses are analyzed by reviewing both quantitative and qualitative data. Trends among the student participants and their perception of value and academic growth were viewed. Quantitative responses were summed up and compared to track trends amongst the students. Qualitative data from the open-ended questions was viewed thematically and will be analyzed using the method of thematic analysis. This process involves the compilation of the responses, decomposition into keywords that have context to the question, categorization into themes, and comparison to other responses amongst the group of students [15].

Due to the small sample size of students, reports of statistical significance are not included in this study, as it is a pilot study to provide insight and advise future research directions.

3. RESULTS

Based on the survey responses, the authors compiled demographic data and participants' contributions, skills, and experiences related to the project and competition. These results provide valuable insight into the educational and developmental impact of the team.

3.1. Demographics

This section outlines demographic information about the students. The first demographic recorded is the student major, shown in Figure 1. Out of the twelve participating students, ten are mechanical engineering (ME), one is electrical engineering (EE), and one is studying engineering physics (EP). Figure 2 shows the academic year, or how far the students are in their degree program. Two of the students are in their 2nd year, two are in their 3rd year, four are in their 4th year, and four have been studying at the university for five or more years. The next two demographics inquired about the student's likelihood of continuing participation in the team during the 2024-2025 academic year. Figure 3 shows how many of the students plan on continuing participation in the team during the next academic year. There is also a comparison of students per academic year and the number of students continuing, seen in Figure 4.

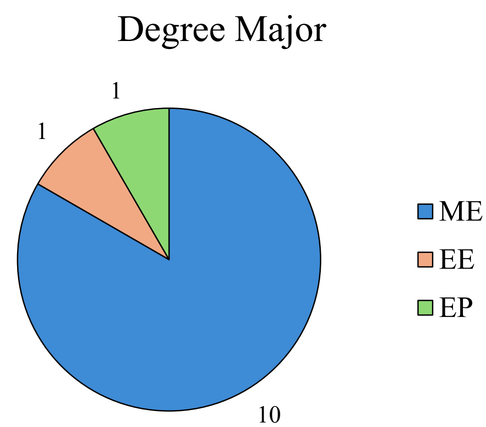

Figure 1: Student Degree Breakdown

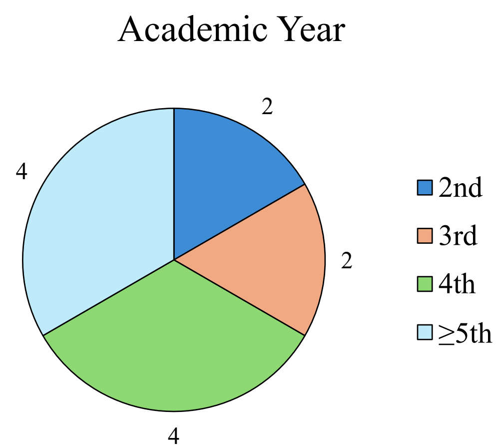

Figure 2: Student Academic Year Breakdown

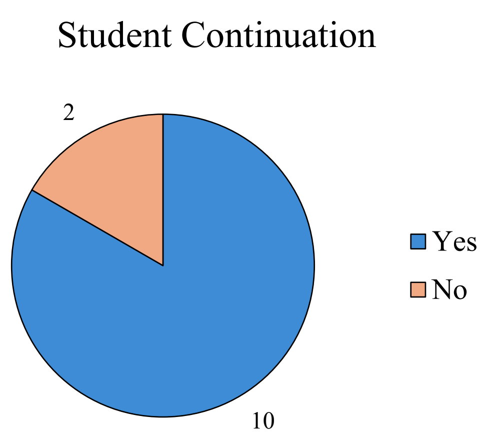

Figure 3: Student School/Team Continuation

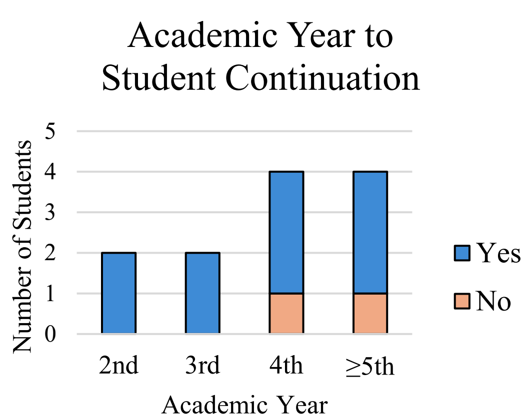

Figure 4: Student Academic Year to School/Team Continuation

3.2. Team Participation

The next set of questions inquired about the students' commitment or participation while on the team. This includes the number of days per week the students spent working on the project during both the spring and summer 2024 semesters (Figure 5). In this figure, the blue represents student participation during the spring semester of 2024, while the orange represents the student participation in the summer semester of 2024. The figure shows increased participation during the summer, most likely due to the lack of classes.

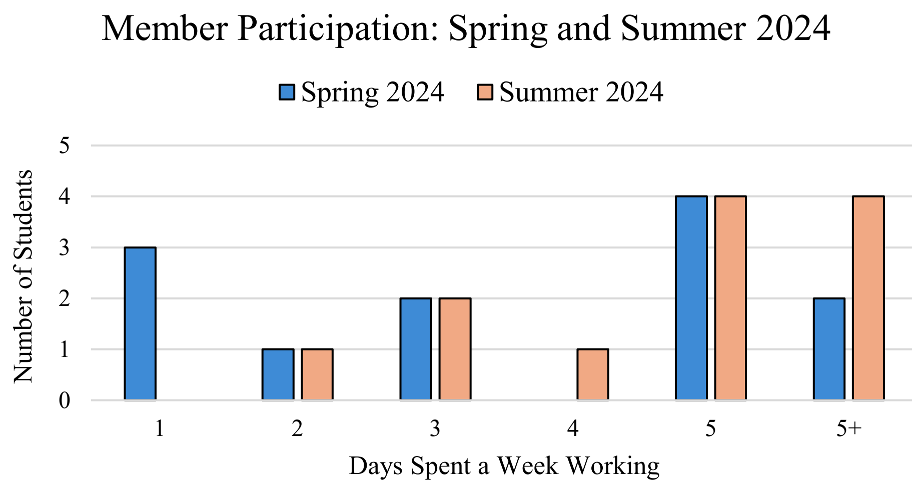

Figure 5: Member Participation in the Spring vs. Summer 2024

Next, the member participation was examined with respect to academic year. Figure 6 shows participation in the spring and Figure 7 shows participation over summer. For both figures, blue represents the number of 2nd year students, orange for 3rd year students, green for 4th year students, and light blue for students who have studied for 5 or more years at the university.

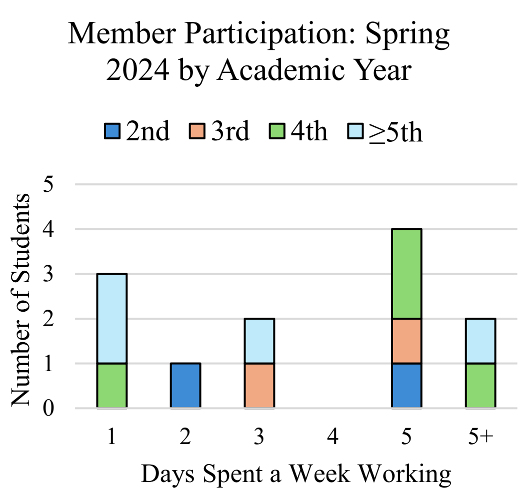

Figure 6: Member Participation in Spring 2024 by Academic Year

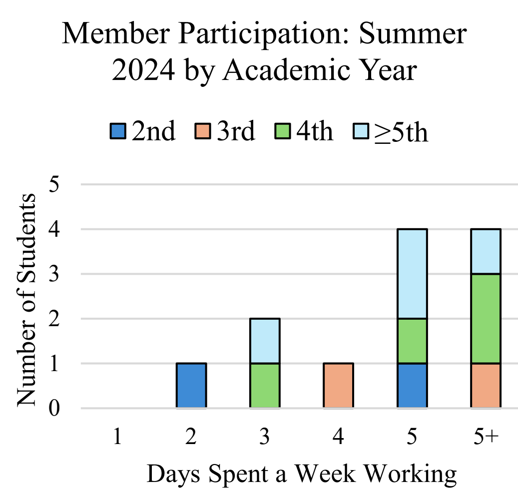

Figure 7: Member Participation in Summer 2024 by Academic Year

3.3. Skills

The data regarding the skills students hoped to learn or acquired was analyzed through multiple lenses. First, the survey examined which subgroups or technical areas students expressed interest in contributing to in the future. This provided insight into their evolving interests and potential growth pathways. Second, the analysis focused on the skills students reportedly gained during the previous academic year, specifically through hands-on involvement with the solar car project.

Figure 8 shows the students' desired subgroup for the next academic year. The students were permitted to choose more than one subgroup, making the total larger than the sample size of the study.

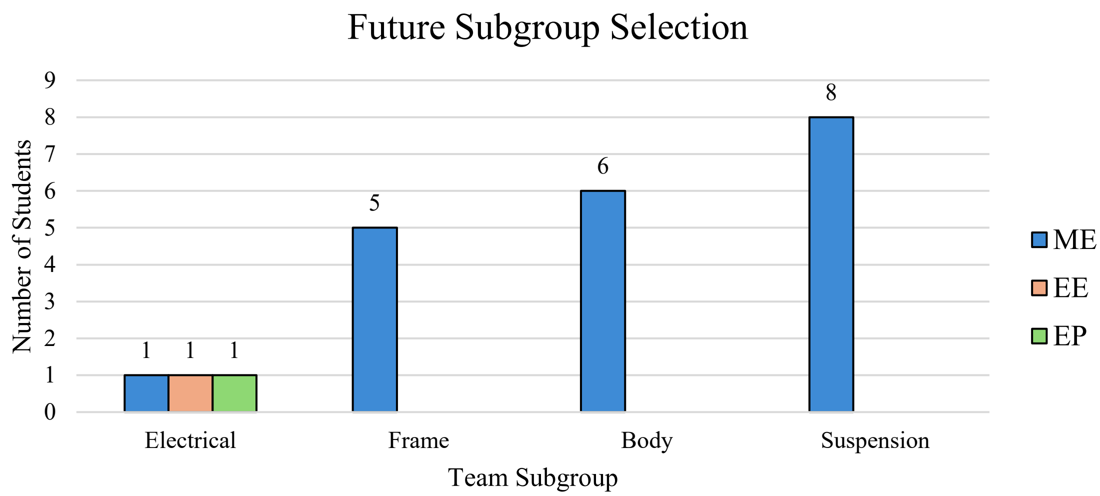

Figure 8: Subgroup areas students want to learn

Next, the learned skillset was viewed and categorized into technical skills and soft skills. These skills are listed out in the below Table 1. The 'Skill' column has each specific skill, while the 'Number' column signifies the frequency that students reported those skills. Students were allowed to list multiple skills in both categories.

Table 1: Technical and Soft skills learned

Technical Skills:		**Soft Skills:**	
Skill:	**Number:**	**Skill:**	**Number:**
Fabrication	7	Communication	8
Computer Aided Design (CAD)	6	Problem Solving	5
Composites	6	Teamwork	4
Body Work	4	Adaptability	4
Suspension Design	3	Management	3
Soldering	2	Networking	3
Circuit Design	2	Conflict Resolution	3
Frame Design	2	Time Management	1
Energy Management	1		
Power Systems	1		
Finite Element Analysis (FEA)	1		
Computer Numerical Control (CNC) Programming	1		
Welding	1		
Documentation	1		

3.4. Project Experience

Students were asked about the benefits of the project, including whether the project increased their academic or professional opportunities, shown in Figure 9. Students ranked their response on a 1-5 scale, where 1 represents little to no increase and 5 represents a great increase. A professional opportunity could include building a professional network, while an academic opportunity could be directly applied to the classroom or the curriculum being taught in class.

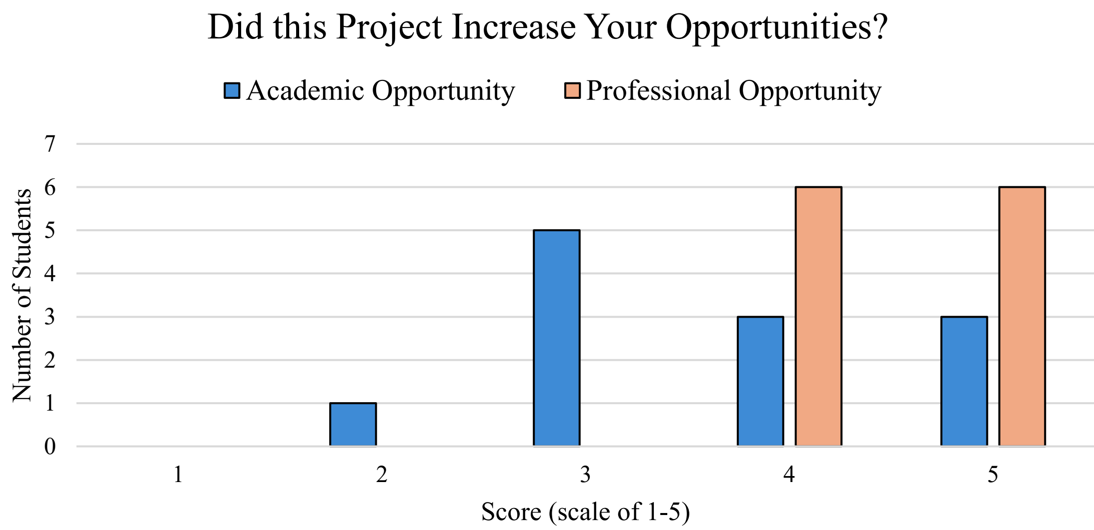

Figure 9: Qualitative examination of academic and professional opportunity

Students were also prompted with an open-ended question that asked if they had anything else to share about their experience while on the team. Students largely expressed praise for the team, summarizing it as fun and fulfilling for most of the students. Responses included “Lots of fun,” “Highly recommend,” and “10/10”. However, also of importance is the feedback that was critical of underlying aspects of the team experience. Two main concerns brought up consistently by team members were the lack of team camaraderie and communication skills.

3.5. Competition Experience

At FSGP, students were exposed to far more than just competition; they also learned about the broader community and its collaborative nature. Participation in the event offered a platform for students to interact with teams from other universities. Through these interactions, students gained valuable insight into aspects of design, manufacturing, and systems integration. This collaboration increased the educational value of the experience and emphasized the importance of groups within the engineering design process.

Figure 10 shows the responses from two of the questions given during the survey. The first being on a scale of 1 to 5, to what extent did the student interact with students from other universities, with 1 being very little or not at all and 5 being a large amount. These responses are shown in blue as the ‘Interaction’ data. The second question inquired to what extent did the interactions with the other students from other universities feel valuable or rewarding, with 1 being very little or not at all and 5 being extremely valuable/rewarding. These responses are shown in orange as the ‘Interaction Value’ data. Table 2 lists some of the primary information that students were able to gain from these interactions to help them plan better for the future of the team.

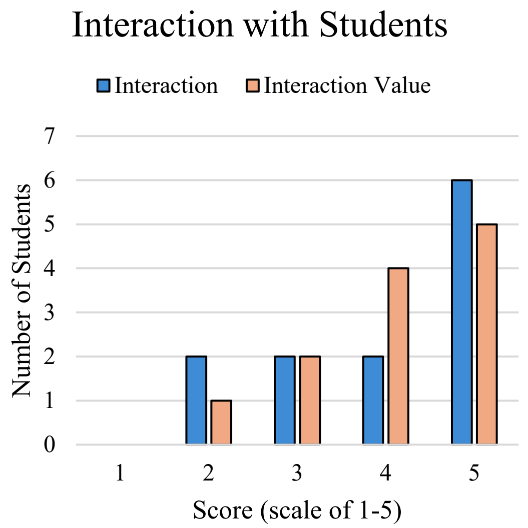

Figure 10: Value of Interaction with students from other universities

Table 2: Key Information from outside interaction with students from other universities

Key information learned from interactions:	
Manufacturing methods	Better utilization of materials
Design ideas	Sponsorships
Battery Protection System (BPS)	Battery Management System (BMS)
Frame design	Aeroshell design
Electrical design	Battery
Optimization methods	Team management
Electronic systems	Suspension design
Material selection	Networking

Throughout the entirety of the event, students were exposed to the nature of the competition where they then became motivated to do more for their team and themselves. The competitive environment was inspiring to them, increasing their motivation to succeed. The responses regarding how motivated students felt due to the competition are depicted in Figure 11, with 1 being little to no motivation gained and 5 being extremely motivating. Table 3 lists some of the primary areas that the students felt were more motivated to complete. These responses were the most common amongst the responses from the survey.

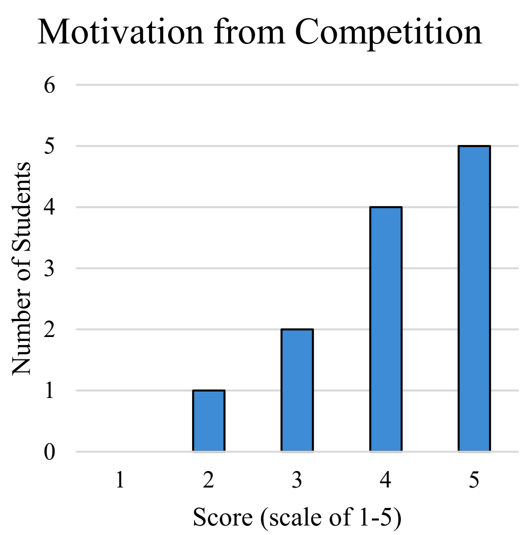

Figure 11: Student Motivation from Nature of Competition

Table 3: Motivation from the competitive nature of the event

Motivation from competition nature:

- Get the car running
- Energy management
- Create future opportunity
- To work harder for success
- Getting more involved in the design and manufacturing process
- Maintain vehicle functionality

While motivated, students also found that this project was a real-world application in which they were able to use what they learned. The level of preparedness for post-graduation is shown in Figure 12, with 1 being little to no preparation and 5 being extremely prepared. From the students that participated in the event, they also responded with the different skills that they felt the event prepared them with, shown in Table 4.

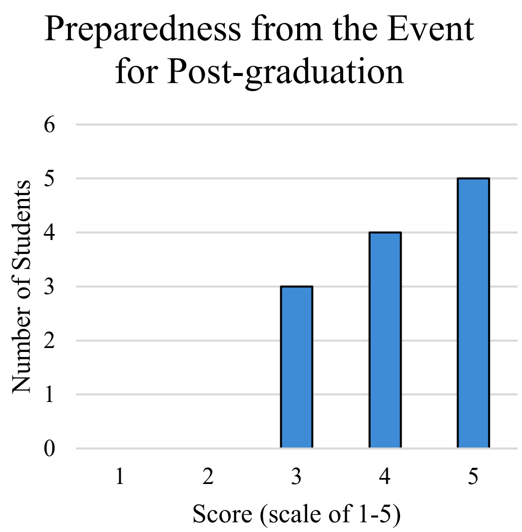

Figure 12: Distribution of preparedness from the event for engineering career post-graduation

Table 4: Preparation for engineering career post-graduation from in-person event

Preparation for an engineering career:

- The real world has stressful situations
- Teamwork
- Networking
- Problem solving skills
- Be open to creativity and different processes
- Application of theoretical knowledge

While at the event, students were not only able to obtain new knowledge and skills, but they also reported their "highlighted events", or moments that stood out to them. These highlights, listed in Table 5, are the most frequently reported amongst the students. Ultimately, these moments are what will drive students to continue the team.

Table 5: Personal highlights from the in-person event

Highlights of event:	
• Getting the car on the track	Repeated in various forms (e.g., "seeing the car move," "the first time seeing our car run on the track")
• Competing with other schools	Highlighted as a memorable experience
• Seeing what we built	A sense of pride in seeing the car in action
• Teamwork and collaboration	Working with team members to accomplish goals
• Learning from other teams	Insights gained from observing and interacting with others
• Overcoming challenges	Specifically related to solving technical problems like implementing the Over Current and Under Current Protection system
• Excitement and success	Examples include emotional moments like "seeing [name] get excited" and the realization they could race

3.6. Team Benefits and Retention

While the students were incredibly positive about their experience on the team, the survey also inquired about areas of improvement for the team. Students who participated at the in-person event identified what they felt needed to be addressed improve team function and retain members, which is listed out in Table 6. The first column represents the most frequently reported improvement areas, while the second column explains the improvement areas with context to the team.

Table 6: Main areas for improvement of the team

Improvement areas:	
• Communication	Improving team communication and reducing misunderstandings. Encouraging better interactions between team members and leadership.
• Organization	Enhancing organization of parts, designs, and team meetings. Structuring subgroups more effectively.
• Leadership and Management	Addressing leadership issues, such as trust and unnecessary conflicts. Improving project and time management, including better design workflows and accountability.
• Design and Technical Improvements	Reducing car weight and improving frame design for efficiency. Enhancing electrical systems, such as better battery protection systems (BPS) and telemetry
• Team Dynamics and Engagement	Increasing member involvement in design tasks rather than relying solely on leads. Retaining students and fostering better teamwork.
• Involvement	Increase outreach opportunities for students at the university with social events or insertion into the curriculum Target the newer students to maintain fresh ideas and keep the retention of students higher and for longer amounts of time

4. DISCUSSION AND CONCLUSION

In this study, we seek to determine the value provided to students from their participation in large format design-build projects. Overall, the students that took part in the in-person competition event found that they benefitted from this experience on the team. All the students involved were engineering majors, possessing technical competencies to complete a project of this scale. Many of the students were upperclassmen, affording them the opportunity to apply their knowledge to this project. Since this group was primarily ME students, they had contributed to much of the overall design and manufacturing of the vehicle throughout the course of the build season.

Of the students that attended, there was a very definitive split between how many days per week they could participate. Figures 5, 6, and 7 show a reduced participation during the Spring semester than Summer. This was to be expected, as they had classes and much busier schedules during the academic year. Even though this was the common trend amongst the cohort of students, upperclassmen exhibited higher participation in both semesters. The authors theorize a few possible reasons for this increased contribution. First, all the team leadership roles are held by upperclassmen that have been involved in the team; leadership roles naturally require higher engagement. This could also be that the upperclassmen have more experience with team-based design projects, possibly possessing higher motivation to complete the project. The upperclassmen students might also have better time management skills, or more time to dedicate to the project, as they are more acclimated to the collegiate environment.

The results also show that students felt they benefited greatly and obtained numerous skills throughout the process. The students going into this project or joining the team primarily wanted to learn new skills that pertained to their degree plan, as seen in Figure 8. Of the self-reported skills in Table 1, students were able to learn several skills that are not typically taught in the classroom. This reinforces the importance of design projects for the formation of these professional and personal skills [1], [2], [3], [8].

Students have also reported numerous opportunities that have been presented to them due to their involvement in this project team. This could be due to multiple reasons: networking, development of new interests, or skill development. Students were asked how much they felt their future opportunities have increased, both academically and professionally. When referring to Figure 9, only some of the students truly felt that their academic opportunities have increased from their participation in the project. On the other hand, students felt that their professional opportunities have increased, as this is experience in a real-world setting, helping them in their future engineering careers while working with interdisciplinary teams [5].

The experience that students gained from the in-person event at FSGP was shown to be extremely beneficial to their STEM education. During the competition, students were able to learn from other university teams and gain more perspective and knowledge regarding solar car racing shown in Figure 10 and Table 2. Students felt that this information was valuable because when students participate in design-build competitions they are exposed to an environment where they must be creative and innovative at the same time. Interaction within the student groups also allows them to network and build relations [3], [7]. While at the competition, students develop a competitive spirit, which influences their motivation. This helps students take what they know and apply it, then apply it back to their STEM education [12]. In Table 3 and Figure 11, students were found to have an increase in motivation to apply themselves more both in the competition and outside of it because of the competition nature. In addition to increasing students' motivation, Figure 12 shows that students also found that the experience benefited them because it gave them a level of preparedness for their engineering careers in post-graduation. The competition also served as a realistic simulation of future engineering careers, exposing students to the pressures, complexities, and communication demands inherent in professional engineering environments. Through this experience, students gained a deeper understanding of the stressful yet rewarding nature of high-stakes project work. Additional insights into their preparedness and expectations are summarized in Table 4 [6]. Students reported one moment that was prominent during the competition, shown in Table 5, which will help drive students to more work like this in the future [12].

Student attrition is common in STEM education, which is also true in extracurriculars. Students were given the opportunity to report areas of improvement (Table 6), which will benefit the team going forward and help them maintain future members. With this information, the team management will rework the structure of the team to help educate new members and keep them more informed and motivated [13], [14]. Using student feedback on the solar car racing team, it was found that a design-build project with an interdisciplinary team is extremely beneficial and valuable to the students' education. This information will be further examined to increase the value of projects for students.

4.1. Future Work

As student participation in this project was found to be beneficial and that this was a preliminary study, future studies will expand upon these members' and future members' experiences and find more trends to offer insight. This study was conducted using a small sample group, which will require further investigation to determine further results or trends. The data was limited, being disseminated as a single survey that occurred after the competition. In the future, the study could be expanded to determine student learning and progression. This could be done using multiple surveys, examining students' academic trajectory and progress as they gain more skills and knowledge on the team. This would allow the research team to determine educational milestones and their benefit. It would also be beneficial to survey other team members that did not attend the competition to determine whether there are significant differences between students.

Future work also includes the expansion of qualitative data analysis. One approach might include coding some sort of machine learning program to better determine features in the data that the research team might not see. Another approach would include the use of a software known as Nvivo, which is a Qualitative Analysis Software (QDA) that can identify different themes and evidence-based insights [16].

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