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Streamlining an Engineering Summer Camp with Engineering Management and Operational Methodologies

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Abstract

For several years, Tennessee Tech University (Tech) has hosted an engineering summer camp for rising 10th, 11th, and 12th-grade students. The camp provides participants with an opportunity to explore the university's seven engineering, engineering technology, and computer science programs, fostering both interest and foundational knowledge in these fields. As a culminating benefit, rising 12th-grade students get a College of Engineering scholarship. In an effort to increase incoming first-year student enrollment, broaden the recruitment area, reduce the overall camp cost, and improve participant student experiences, the College of Engineering leadership streamlined the program. The goals were to enhance diversity in applicant pools, increase engagement with various sectors of the engineering community, reduce the workload on faculty and staff, and improve the efficacy of students in applying engineering concepts. To achieve these objectives, the College implemented Lean Systems principles alongside other engineering management methodologies. This paper outlines how the application of resource optimization, stakeholder engagement, improved communication flow, and continuous improvement processes have not only improved the overall camp experience but also significantly enhanced students' efficacy in grasping and applying engineering skills. As a result, the number of camp participants has quadrupled over four years.

Keywords

Engineering Summer Camp, Program Streamlining, Lean Systems, Student Engagement, Operational Efficiency, Continuous Improvement.

1. Introduction

Engineering summer camps have long served as a dynamic gateway for cultivating students' early interest in STEM fields, particularly engineering. Through immersive, hands-on activities and personalized interactions with faculty, these programs give young learners a chance to explore various disciplines—including mechanical, electrical, civil, and computer engineering—and gain insight into potential career paths. Recent studies underscore the power of well-designed summer camps to spark curiosity, strengthen self-efficacy, and shape academic aspirations, especially among students who might otherwise lack exposure to the breadth of engineering [1-5]. Yet, growing student populations, evolving technological demands, and finite institutional resources necessitate a reevaluation of how these camps are planned, executed, and continually improved. How can institutions broaden participation, manage costs effectively, and still preserve—or even enhance—the learning experience for aspiring engineers?

In response to these challenges, educational leaders are increasingly turning to established process improvement methodologies—such as Lean Systems, Six Sigma, and Lean Six Sigma—to optimize both academic and operational facets of engineering outreach [6-8]. While these methods originated in manufacturing and business, research demonstrates that they also offer considerable potential for improving program efficiency, stakeholder engagement, and resource utilization in higher education [9-11]. Focusing on value creation, continuous improvement, and minimization of waste, Lean-based frameworks can help administrators tackle the complex logistics of running a summer camp: scheduling faculty, coordinating facilities, ensuring the availability of lab equipment, and accommodating the diverse learning needs of participants.

This paper examines a large-scale engineering summer camp at Tech, where the College of Engineering embarked on a comprehensive effort to expand the camp's reach, diversify its applicant pool, and ease the workload on faculty and staff. By systematically integrating Lean and engineering management methodologies, the program significantly reduced operational inefficiencies while still delivering engaging, hands-on experiences for participating students. Over four years, camp enrollment quadrupled, and anecdotal evidence suggests that students not only enjoyed the camp atmosphere but also gained deeper insights into fundamental engineering concepts.

In the sections that follow, we review relevant literature that guided our framework, detail the specific methodologies employed, and share key observations from the camp's transformation. We conclude by offering insights and best practices for other institutions seeking to implement Lean-driven improvements in their own outreach efforts. Through this fusion of operational efficiency and high-impact learning, engineering summer camps can continue to grow—both in quality and inclusivity—ultimately inspiring the next generation of problem solvers.

2. Literature Review

Robinson et al. examines the impact of engineering summer camps on middle and high school students' interest in and identification with engineering [1]. Findings indicate that camp activities effectively trigger and sustain interest, even among those with no prior exposure, and support participants' identification with engineering as a field. However, limitations include small sample sizes for some analyses, potential participant selection bias, lack of long-term follow-up, and demographic mismatches compared to broader populations. Despite these limitations, the study underscores the importance of intentional camp design in fostering interest and future exploration of engineering careers.

Summer camps are a well-established tool for promoting STEM disciplines, particularly engineering, as part of broader recruitment efforts like K-12 outreach and workshops [2]. Programs targeting women and minorities have proven effective in influencing career choices. The University's College of Engineering runs two summer programs: HI-GEAR for academically strong female students, and Exploring Engineering Camp, which introduces high school students to various engineering disciplines. Changes over three years increased community popularity and attendance, with 20% of attendees (2008–2012) becoming engineering majors at the University. The 2015 STEPS summer camp for rising seventh graders, organized by the University of St. Thomas in collaboration with the St. Paul Public Library, emphasized hands-on learning with lessons in basic circuitry, laser cutting, and engineering design [3]. Targeting underrepresented groups, the camp incorporated best practices from pre-college STEM education research and Next Generation Science Standards. Pre- and post-surveys revealed that 88.5% of participants experienced no change or an increase in confidence in their engineering skills. Key program updates included partnerships to foster cultural competence, constructivist learning, and community support. The synergy between university and library partnerships provided students with inspiring experiences, encouraging them to envision engineering careers.

Hammack et al. examined how a week-long engineering camp influenced middle school students' attitudes toward engineering and their understanding of engineering and technology [4]. The camp positively impacted perceptions of technology and engineers' work, though the specific components driving these changes were unclear. Limitations included a small sample size and short-term focus. Khalafalla et al. studied a similar camp at Florida A&M University targeting underrepresented minority high school students [5]. Hands-on activities, trivia games, and team-building exercises improved students' STEM understanding, teamwork, and confidence. The study highlights the value of engaging activities and diverse participation in fostering STEM interest.

A paper by Vukadinovic et al. explores how Lean philosophy can improve engineering education by preparing professionals for dynamic Lean environments through the development of multidisciplinary knowledge and skills [6]. The authors review literature on Lean's impact on engineering education and its benefits for modern Lean enterprises. They emphasize that the growing demand for engineers with broad competencies, including Lean skills, has driven the need for curriculum reforms in academic institutions. By applying Lean principles, educational systems can become more efficient, minimizing waste and enhancing the value provided to students and industry.

Yalçın Tilfarlıoğlu examines the adaptation of Lean principles to education, emphasizing their potential to eliminate waste, enhance individual performance, and foster a culture of continuous improvement in educational systems [7]. Lean encourages efficient use of resources, empowering all stakeholders-students, teachers, parents, and administrators—to achieve top performance by focusing on value-adding activities. The study highlights the importance of using human resources effectively, minimizing time waste, and promoting problem-solving and personal growth in educational contexts. Douglas et al. focuses on translating the eight wastes of Lean into higher education institutions (HEIs) and proposes Lean solutions to address them [8]. The authors identify examples of waste in academic and support services, such as excessive movement, overproduction of materials, and wasted human resources. Lean solutions like 5S, process mapping, and level scheduling are recommended. The paper emphasizes how Lean thinking can help HEIs reduce waste, cut costs, and improve performance, particularly during times of constrained resources and government funding cuts. A holistic approach to applying Lean across both academic and administrative functions is highlighted.

Antony et al. (2007) reviewed the application of Six Sigma in the UK service sector [9], highlighting key challenges, myths, and implementation issues. The study identified critical success factors, including management commitment, customer focus, strategic alignment, organizational infrastructure, and project management skills. Findings revealed most organizations had implemented Six Sigma for over three years, achieving an average sigma quality level of 2.8 (98,000 DPMO). This work provides valuable insights for academics and practitioners into Six Sigma's role in improving service performance. In their work, Antony et al. evaluates the potential of Lean Six Sigma (LSS) as a business improvement methodology to enhance the efficiency and effectiveness of HEIs [10]. It explores challenges, barriers, critical success factors, and useful tools for LSS implementation in HEIs. The study highlights the applicability of LSS beyond manufacturing, emphasizing its role in waste reduction, variability control, and improving student satisfaction. While the findings are theoretical, they provide a foundation for future empirical research to develop practical roadmaps for LSS adoption in HEIs.

Hargrove and Burge [11] proposed using industry-based Six Sigma methodologies to address low retention rates among underrepresented minority students in science and engineering education. They highlighted significant disparities in graduation rates-approximately one-third for minority students compared to two-thirds for non-minority groups. Their approach aims to assess, monitor, and improve student performance systematically. A pilot study explored its potential in increasing retention and meeting the industry's demand for skilled professionals.

The project discussed in this paper was revamped in 2023 using these lean principles to reduce waste and broaden the summer camp's reach.

3. Methodology

This study employed 5S and Lean concepts to improve the operational efficiency and participant experience of a summer camp program. The methodology focused on systematically analyzing and redesigning the camp schedule and activities to eliminate waste, standardize processes, and enhance value delivery. The pre-COVID-19 summer camp schedule (Figure 1) was analyzed to identify inefficiencies, including overlapping activities, excessive downtime, and unclear transitions between sessions. The assessment also considered feedback from past participants and staff. The Sort-Set in Order-Shine-Standardize-Sustain steps of the 5S concept, a fundamental Lean methodology, were implemented to identify improvement opportunities in the summer camp program. Based on the analysis of pre-COVID summer camps, 5S was applied as follows to enhance the post-COVID camps

1. *Sort:* Unnecessary or redundant activities, such as overlapping sessions and prolonged free periods, were identified and eliminated.
2. *Set in Order*: Activities were reorganized into a logical sequence, ensuring smooth transitions and optimized use of time and resources.
3. *Shine*: Camp facilities were evaluated and organized to ensure cleanliness and functionality, supporting a more efficient and enjoyable environment for participants.
4. *Standardize:* Standard operating procedures (SOPs) were developed for core activities, ensuring consistency in delivery and minimizing confusion among staff and participants.
5. *Sustain:* A monitoring system was implemented to regularly review the updated processes and ensure adherence to the new schedule.

The implementation of 5S not only streamlined activities but also enhanced the administrative workflow. For example, eliminating redundant tasks reduced counselors' workload, allowing them to focus more on student engagement. Reorganizing schedules facilitated smoother transitions, minimizing downtime and confusion for both participants and staff. By standardizing procedures, communication flow among counselors and administrators was significantly improved, leading to more cohesive team operations and better resource allocation.

	Sunday		Monday		Tuesday		Wednesday		Thursday		Friday		Saturday	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
7:00 AM			Breakfast		Breakfast		Breakfast		Breakfast		Breakfast		Pack to go home/ Sleep in	
7:30 AM														
8:00 AM			CSC Overview	MET	MET	CSC Overview	CEROC Activity	MET	MET	CEROC Activity	isit Bookstore if Intereste			
8:30 AM														
9:00 AM														
9:30 AM			Restroom/Free		Restroom/Free		Restroom/Free		Restroom/Free		Walk to STEM Center			
10:00 AM			ME - Intro to ME (combined)		ME (Design)	ME (Career/Research)	ME (Career/Research)	ME (Design)	ME Lab Tours	ME Lab Tours	ME (Competition-combined)		Brunch	
10:30 AM														
11:00 AM														
11:30 AM			Restroom/Free		Restroom/Free		Restroom/Free		Restroom/Free				Parents Arrive	
12:00 PM	Counselors Arrive		Lunch (Alums visit)		Lunch (Alums visit)		Lunch (Alums visit)		Lunch (Alums visit)		Lunch (Alums visit)		Check-Out	
12:30 PM													Closing Ceremony	
1:00 PM	Check - In		Civil Build Balsa Wood Bridges	Computer Engineering	Computer Engineering	Civil Build Balsa Wood Bridges	Civil Test Bridges	Electrical Engineering	Electrical Engineering	Civil Test Bridges	TC 1:00 - 2:30 Location T			
1:30 PM														
2:00 PM														
2:30 PM				estroom/Fre	estroom/Fre		Restroom/Free		Restroom/Free		Restroom/Free			
3:00 PM	Group Photo			Chemical Engineering	Chemical Engineering		ME Additional Build Time	Chemical Engineering	Chemical Engineering	ME Additional Build Time	Admissions Overview			
3:30 PM	Welcome													
4:00 PM	General Engineering													
4:30 PM	Ice Breakers			Free Time				Free Time	Free Time					
5:00 PM	Dinner (Alums visit)		Free Time		Multicultural Affairs									
5:30 PM														
6:00 PM	Rock Wall		Dinner (Alums visit)		Dinner (Alums visit)		Dinner (Alums visit)		Dinner (Alums visit)		Dinner (Alums visit)			
6:30 PM														
7:00 PM			Engineering Competition		Engineering Competition		Engineering Competition		Engineering Competition		Movie and Icecream Night			
7:30 PM														
8:00 PM														
8:30 PM														
9:00 PM														
9:30 PM														
10:00 PM														
10:15 PM	Fire Drill													

Figure 1: Summer Camp Schedule pre COVID-19

	Sunday	Monday				Tuesday				Wednesday			
		Group-1	Group-2	Group-3	Group-4	Group-1	Group-2	Group-3	Group-4	Group-1	Group-2	Group-3	Group-4
7:00 AM		Breakfast				Breakfast				Breakfast			
7:30 AM													
8:00 AM		ME Intro				Honors				Admissions			
8:30 AM													
9:00 AM		ME Des	CSC	MET	ChE	CSC	ME Des	ChE	MET	ME Test			
9:30 AM													
10:00 AM													
10:30 AM		Break				Break				Break			
11:00 AM	Counselors Arrive	MET	ChE	ME Des	CSC	ChE	MET	CSC	ME Des	CEE Test			
11:30 AM													
12:00 PM		Lunch (Alums visit)				Lunch (Alums visit)				Lunch (Alums visit)			
12:30 PM													
1:00 PM	Dorm check-in												
1:30 PM													
2:00 PM	Welcome & Orientation	CEE Des	CEE Des	ECE	Maker-space	ECE	Maker-space	CEE Des	CEE Des	CSC			
2:30 PM													
3:00 PM	Intro to ENGR session									Dorm Check-out			
3:30 PM				Break		Break							
4:00 PM	Ice Breakers/Group Photo before Dinner	Break		Maker-space	ECE	Maker-space	ECE	Break		Closing Ceremony			
4:30 PM		Inter Cultural	Inter Cultural					Inter Cultural	Inter Cultural				
5:00 PM	Dinner (Alums Visit)												
5:30 PM		Break				Break							
6:00 PM		Dinner (Alums Visit)				Dinner (Alums Visit)							
6:30 PM	Burnett Fitness Center												
7:00 PM		Activity Time				Activity Time							
7:30 PM													
8:00 PM													
8:30 PM	Get Ready for Bed	Get ready for bed				Get ready for bed							
9:00 PM													
9:30 PM	Lights Out	Lights Out				Lights Out							

Figure 2: Summer Camp Schedule in 2024

Identifying value-added and non-value-added activities, as well as *eliminating waste,* are fundamental Lean concepts. Tools like *Value Stream Mapping* (VSM) and *Gemba Walks* are commonly used to achieve these objectives. In this work, a Gemba Walk was employed to systematically evaluate the camp's operations. Staff observed activities in real-time, identifying inefficiencies and unnecessary steps. For instance, extended administrative tasks were identified as non-value-added, creating bottlenecks. These tasks were streamlined or automated, reallocating resources to high-impact activities that directly enhanced the participant experience.

This targeted approach demonstrates how integrating VSM principles with actionable insights from a Gemba Walk can drive significant operational improvements by eliminating waste and prioritizing value delivery. The concept of *Continuous Improvement* was applied through incremental changes during the camp's implementation, driven by continuous feedback from staff and participants. This approach ensured that improvements were both sustainable and impactful. Quantitative data, including participant satisfaction scores and activity completion rates, were collected before and after implementing the improvements. Qualitative feedback was obtained through surveys and interviews with participants and staff to assess the perceived benefits of the changes. Figure 2 illustrates the 2024 summer camp schedule, streamlined through the application of Lean system concepts and methodologies to optimize operations and activities.

4. Results & Observations

Figure 3 shows the number of participants in the summer camp over the years since 2018. The camp schedule was almost the same in 2018 and 2019. The camp transitioned to online format in 2020 and 2021 due to COVID-19, but the schedule effectively remained the same. The number of participants increased slightly to 60 in 2022. After the overhaul and optimized schedule as in Figure 2, the camp attracted more applications and participants in 2023 and 2024. Table 1 provides the gender representation among summer camp participants in 2018 and 2024. In 2018, with 24 attending campers, 15 (63%) were male, while 9 (38%) were female. In 2024, with 259 attending campers, 190 (73%) were male, while 69 (27%) were female. Table 2 presents the race and ethnicity distribution of summer camp participants in 2018 and 2024. Overall, the increase in the size of camp showed a wider range of ethnic and racial backgrounds. While the percentage of female campers decreased, the larger number of attendees overall should increase the yield of women and underrepresented minorities. The number of applications, acceptance, and participants in the 2024 summer camp are presented in Table 3, demonstrating extensive interest among high school students.

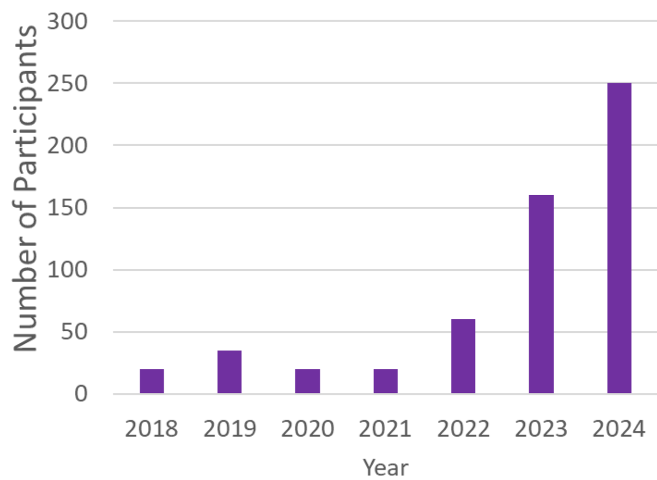

Figure 3: Trend of increasing number of participants in the annual summer camp

Table 1: Gender Representation Among Summer Camp Attendees

Year	2018	2024
Male	15	190
Female	9	69
Total	24	259

Table 2: Race and Ethnicity Distribution of Summer Camp Participants

Year	2018	2024
Black or African American	10	24
Hispanic or Latino	2	16
White	12	190
American Indian	-	4
Asian	-	20
Native Hawaiian or Pacific Islander	-	1
Other	-	4
Total	24	259

Table 3: Numbers on applications, acceptances, and participation in 2024 summer camp

Month	Applications	Acceptance	Confirmations
June	298	180	130
July	216	160	111
Total	514	340	241

Table 4 presents the post-survey results from student participants in 2018, with only 24 students. While the results were positive overall, the effort was highly demanding. Results from the 2024 summer camp (after optimization) are presented in Table 5 and Table 6. The results from pre- and post-tests, workshop feedback, and participant surveys demonstrate the effectiveness of the engineering summer camp program in fostering interest, confidence, and understanding of engineering concepts among participants. Feedback from various workshops highlights high levels of engagement and learning outcomes. For example, 84% of participants in the Chemical Engineering workshop reported enjoying the activity, with 76% agreeing it enhanced their understanding of chemical engineering. Similarly, the Civil Engineering workshop's balsa wood bridge activity effectively conveyed key concepts such as "force" (75%) and "compression" (73%), with 86% of participants expressing enjoyment. Electrical and Computer Engineering workshops also received positive feedback, with 83% of attendees enjoying the activities and 87% agreeing they effectively promoted understanding. Other disciplines, including Computer Science, Engineering Technology, and Mechanical Engineering, exhibited similar patterns, with engagement and understanding metrics typically exceeding 70%. However, participants suggested areas for improvement, with 47% to 63% across disciplines indicating enhancements could further enrich the learning experience.

Table 4: Survey results from summer camp in 2018 *(N=24)*

Program	**% of students responding "somewhat agree" or "strongly agree" to the item, "The workshop was interesting,"**
Chemical Engineering	73.7%
Civil Engineering	100%
Computer Science	76.5%
Electrical and Computer Engineering	84.2%
Engineering Technology	94.4%
Mechanical Engineering	94.1%

Table 5: Program-specific survey results from one summer camp in 2024

Item	**# and % of students who agreed or strongly agreed with the statement**
Chemical Engineering (N=100)	
I enjoyed this activity.	84 (84%)
The activity was effective in engaging and promoting understanding of chemical engineering concepts.	91 (91%)
The activity could be improved to enhance the learning experience.	52 (52%)
The activity helped me better understand the discipline of chemical engineering.	76 (76%)
Civil Engineering (N=56)	
The bridge activity effectively explained how "estimation of maximum load" works.	36 (64%)
The concept of "force" was clearly conveyed through the balsa wood bridge activity.	42 (75%)
The concept of tension was effectively illustrated during the activity.	31(55%)

The activity successfully demonstrated the concept of compression	41 (73%)
The balsa wood bridge was effective in engaging and promoting understanding of civil engineering concepts.	45 (80%)
The maximum load of the bridge could be improved to enhance the learning experience.	40 (71%)
The activity helped me make connections between the activity and the discipline of civil engineering.	43 (77%)
I enjoyed this activity.	48 (86%)
Computer Science (N=76)	
I enjoyed this activity.	66 (87%)
The activity was effective in engaging and promoting understanding of computer science concepts.	69 (91%)
The activity could be improved to enhance the learning experience.	41(54%)
The activity helped me better understand the discipline of computer science.	66 (87%)
Electrical Engineering (N=75)	
I enjoyed this activity.	62 (83%)
The activity was effective in engaging and promoting understanding of chemical engineering concepts.	65 (87%)
The activity could be improved to enhance the learning experience.	47 (63%)
The activity helped me better understand the discipline of chemical engineering.	64 45%)
Engineering Technology (N=79)	
I enjoyed this activity.	64 (81%)
The activity was effective in engaging and promoting understanding of chemical engineering concepts.	59 (75%)
The activity could be improved to enhance the learning experience.	37 (47%)
The activity helped me better understand the discipline of chemical engineering.	56 (71%)
Mechanical Engineering (N=74)	
I enjoyed this activity.	51 (69%)
The activity was effective in engaging and promoting understanding of chemical engineering concepts.	49 (66%)
The activity could be improved to enhance the learning experience.	47 (64%)
The activity helped me better understand the discipline of chemical engineering.	51 (69%)

Table 6: 2024 Pre- and Post-Survey: Student Interest in the Respective Discipline (N=259)

Major	Pre-	Post
Chemical Engineering	36%	45%
Civil Engineering	51%	48%
Computer Science	50%	56%
Electrical and Computer Engineering	66%	71%
Engineering Technology	60%	62%
Mechanical Engineering	75%	78%

The pre- and post-test comparisons underscore the camp's impact on participants' evolving interest in engineering. Interest in Electrical and Computer Engineering increased from 66% to 71%, while interest in Computer Science rose from 50% to 56%. Furthermore, the likelihood of participants applying to the hosting university grew from 89% in the pre-test to 94% in the post-test, demonstrating the program's success in strengthening participants' connection to the institution.

The structured implementation of Continuous Improvement principles allowed for iterative adjustments throughout the camp, enhancing student engagement and learning outcomes. By continuously gathering feedback from participants and counselors, the camp promptly addressed challenges, thereby sustaining high levels of student interest and participation. Applying standardized procedures (part of the 5S methodology) also provided a consistent learning environment, reducing confusion and enabling students to grasp engineering concepts better. This alignment of Lean practices with educational objectives significantly contributed to the increased efficacy in applying engineering skills, as evidenced by the improved post-survey metrics. Qualitative and quantitative data from the Persistence in Engineering survey revealed positive shifts in participants' perceptions of engineering as a career. After attending the camp, more students strongly agreed that engineering is a rewarding and respected profession contributing to societal improvement. Confidence in pursuing engineering careers also increased, as participants agreed with statements such as "engineering is creative" and "engineering involves finding precise answers to problems."

The camp's ability to attract participants has grown significantly, as reflected in application, acceptance, and confirmation numbers. In 2024, the program received 514 applications, with 340 acceptances and 241 confirmed participants. This growth indicates the success of streamlining operations using Lean methodologies, which have enhanced the camp's appeal while maintaining high levels of engagement.

The integration of 5S and Lean methodologies significantly improved operational efficiency and participant experiences. The camp minimized downtime and enhanced engagement by eliminating inefficiencies, optimizing activity sequences, and introducing standardized communication protocols. Lean tools such as Value Stream Mapping and Gemba Walks were crucial in identifying bottlenecks and reallocating resources to high-impact activities, directly enhancing participant interactions and learning outcomes. Continuous Improvement principles ensured that the changes were sustainable, as incremental updates were informed by ongoing feedback from staff and participants.

In summary, the engineering summer camp program has effectively engaged students across diverse engineering disciplines. Post-test data highlight the program's role in fostering a deeper appreciation for engineering and the hosting university, supporting its value as a recruitment tool. The application of Lean principles has been instrumental in increasing operational efficiency, enabling broader participation, and maintaining high levels of engagement. Continuous improvements will further amplify the camp's impact, inspiring the next generation of engineers.

5. Conclusions

The success of the engineering summer camp program is closely tied to the integration of Lean concepts, which transformed its operational framework and participant experience. Implementing Lean methodologies enhanced operational efficiency, optimized resource utilization, and improved communication flow. Specific Lean practices, such as Gemba Walks for real-time observations and Value Stream Mapping for identifying non-value-added activities, directly improved workflow efficiency and stakeholder engagement. These enhancements optimized camp operations and enriched student interactions and learning experiences, achieving the program's educational and operational goals. This systematic approach fostered deeper participant interest in engineering disciplines and strengthened their connection to the hosting university. By embracing Continuous Improvement principles, the program remains well-positioned to inspire and attract future engineers, ensuring its long-term impact and sustainability.

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