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Bridging Gaps in Robotics Education: Insights from Team Surveys on FIRST Tech Challenge

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Abstract

The FIRST Tech Challenge (FTC) has engaged about 87,400 students from grades 7 to 12 across 67 countries and regions in recent seasons. This competition tests students' mechanical design, programming, and robot operation skills, all within the framework of an alliance-based floor game. Additionally, the FTC emphasizes the broader impacts of a team's outreach activities. Teams advance based on their performance in the robotic game or recognition through awards such as Inspire, Think, Innovate, Control, Connect, Motivate, and Design. Despite the reported outcomes of the FTC program, few studies have explored FTC teams' perspectives on their efforts, challenges, and resources. This study addresses the gap by surveying a large sample of FTC teams to identify the factors contributing to their growth.

A comprehensive survey was distributed to 264 FTC teams during the 2022 - 2023 season and 344 teams during the 2023 - 2024 season. One hundred eighty-four responses were collected from state and world competitions in 2023, and 267 were gathered at regional, state, and world championships in 2024. The survey covered 11 key metrics, examining team attributes such as whether they are school-affiliated or community-affiliated, team size, FTC experiences in years, training in technical and soft skills, team efforts, the culture of team collaboration, and available resources. Statistical analysis was conducted to understand differences among teams attending regional, state, and world competitions.

This paper presents the first study on the quantitative analysis of team attributes in FTC robotics competitions. We evaluated team performance at the regional, state, and world levels, quantifying improvements observed at each stage. Our survey reveals significant differences in weekly effort and training between teams that advanced to the world championships (9-12 hours per week) and those that did not.

The insights gained from this study provide valuable guidance on FTC team coaching and management, benefiting FTC coaches, team members, and event coordinators. Our findings suggest several key factors contributing to the growth and advancement of FTC teams to world-level competitions, including (1) consistent participation in off-season activities, (2) specialized technical training in programming, odometry, CAD, camera/image processing, and control, and (3) structured soft skills training in documentation and presentation. Notably, community-affiliated teams may have an advantage in these areas, as a greater number of them have advanced to world championships. By offering a data-driven perspective on training strategies, time allocation, and task assignments, these findings can help teams refine their preparation, enhance their competitiveness, and improve overall program effectiveness.

Objective and motivation

Children and young adults are increasingly drawn to robotics because it combines creativity, problem-solving, and hands-on learning. By building and programming robots, they apply their knowledge to real-world projects and develop technical skills in coding, math, science, and engineering disciplines. This hands-on experience sparks curiosity about science, technology, engineering, and mathematics (STEM), and prepares children for future STEM-related careers, equipping them with the tools to succeed in electrical engineering, computer engineering, and mechanical engineering [1-3].

Besides the technical skills embedded in building robots, robotic competitions play a crucial role in further engaging children in robotics, fostering innovation, and enhancing soft skills such as teamwork, conflict resolution, and communication [4-7]. While numerous national and international robotics competitions exist [4, 8, 9], we chose to focus our research on the For Inspiration and Recognition of Science and Technology (FIRST) Tech Challenge (FTC) program for its integration of technical skills and soft skills that are important for participants' future career development [10].

FTC participants are 7-12 graders and the competition tests students' mechanical design, programming, and robot operation skills, all within the framework of an alliance-based floor game. Teams advance based on their performance in the robot game and recognition through awards such as Inspire, Think, Innovate, Control, Connect, Motivate, Design, and Gracious Professionalism. These awards are determined based on their engineering portfolio, presentations in a judging room, and the community impact of their outreach activities. The advancement mechanism in the FTC program provides a comprehensive opportunity for students to develop and apply both technical and soft skills through competitions at league, regional, state, and world levels.

An FTC season typically begins in early September, and competitions last anywhere from 4 to 8 months, depending on team performance. Most teams compete in local leagues or regional events until February of the following year, with some advancing to state competitions in March. Around 200 teams then move on to the world championship in April. Out of over 7,600 teams participating in the FTC program globally, about 2.5% make it to the World Championship each year. Since its establishment in 1989, the FTC program has grown to involve approximately 87,400 students in grades 7 to 12 from 67 countries and regions yearly. Over the years, it has drawn millions of students into robotics since its establishment.

The FTC robotics program, along with other studies, has reported its success in attracting K-12 students into STEM fields [7, 11-13]. However, few studies have explored FTC teams' perspectives on their efforts, challenges, and resource availability. This paper addresses this gap by describing a study on FTC team perception. This study surveys a large sample of FTC teams to identify the key factors contributing to a team's success and the essential skills necessary for growth. It also examines the resource distribution of FTC teams within a state in the United States.

Methods

We analyzed team performance across the Central Texas area, state of Texas (United States), and World championships to identify specific attributes emphasized at the state and world levels. For competition management purposes, FIRST in Texas was divided into multiple regions. The region of Central Texas was selected because the number of registered teams is large enough to ensure responses with statistical significance and team accessibility. The survey data was collected over two consecutive seasons, 2022–2023 and 2023–2024. Additionally, we examined the performance of all teams competing in the Texas State Championship and the World Championship in April of 2023 and 2024.

Survey questions

A comprehensive survey was distributed to 264 FTC teams during the 2022 - 2023 season and 344 teams during the 2023 - 2024 season. A total of 184 responses were collected from state and world competitions in 2023, and 267 responses were gathered at regional, state, and world championships in 2024. The survey covered 11 key metrics, examining team attributes such as whether they are school-affiliated or community-affiliated, team size, FTC experience in years, training in technical and soft skills, team efforts, team culture regarding collaboration, and available resources.

Eleven out of twelve survey questions (SQ) are fact-based.

SQ1: What's your team number?
The first question asks for the team number, allowing us to track the team's history and performance on the FTC Stats online database [14].

SQ2: How many team members are there on your team for this season?
Team size is asked to explore whether having more members contributes to better task distribution and overall team performance.

SQ3: Is your team a school-affiliated team? Yes No
If yes, what's your school's name and school district?

This question distinguishes between school-affiliated and community-affiliated teams. School-affiliated and community-affiliated teams are formed differently, leading to various management and communication styles. We included this question to explore whether these differences influence team performance. For questions with "Yes" or "No" options, we assign a score of 0 for "No" and 1 for "Yes" in the quantified survey analysis.

SQ4: How many years of FTC experience do most of your current team members have?

1 year	2 years	3 years
4 years	5 years	Other

This question explores the experiences of an FTC team. Given the long history of the FTC program, some teams have been active for many years. The smaller the team number, the earlier the team joined FIRST competitions. As former team members retire and new ones join, the accumulated parts and experiences can influence a team's performance. Central Texas region

hosts teams with two-digit numbers, reflecting the team's strong sustainability and the sharing of experiences over the past 17 years.

SQ5: Does your team meet off-season?

Yes No

SQ6: How many hours do you meet <u>each week</u> this season?

<3 hours 3-6 hours 6-9 hours
9-12 hours 12-15 hours Other (Please fill in _____)

SQ7: How many hours has your team spent on <u>outreach</u> activities <u>each week</u>?

<5 hours 5-10 hours 10-15 hours
Other: (Please fill in _____.)

SQ8: How many hours has your team spent on team building <u>this season</u>?

<5 hours 5-10 hours 10-15 hours
Other: (Please fill in _____.)

These four questions, SQ5 – SQ8, evaluate the team's efforts during and outside the competition season. Since the FTC program aims to strengthen community impact, the survey also examines the team's involvement in outreach activities.

SQ9: Does your team have training sessions on the following topics?

Encoder Odometry Camera/image processing
Programming CAD CNC Control
Presentation Safety Collaboration Documenting
Other : (Please list _____)
If you have multiple training sessions on a topic, please write the number of sessions.

The survey question, SQ9, assesses the training undertaken by FTC teams in both technical and soft skills. We detail 11 distinct training areas, covering technical skills such as sensor integration, mechanical design, programming, and construction, as well as soft skills like documentation and presentation. These training areas were curated by experienced FTC coaches. Furthermore, teams participating in the survey can report any additional training not captured in the survey.

SQ10: What's the percentage of collaborative work in all your team activities in 2022-2023 season?

<25% 26% - 50% 51%-75% 76% - 90% >90%

This question assesses the level of collaboration among team members.

SQ11: How much money did your team spend this season? Please clarify the currency unit.
This question examines the resources/funding available to the team.

SQ12: What's the most difficult task for your team?
This open-ended question invites FTC teams to share their experiences. The most commonly raised issues will be adopted in future surveys.

Team performance for robot games at regional, state, and world championships

Offensive Power Rating (OPR) is a commonly used metric for assessing team offensive performance in FTC robot games. Non-penalty OPR data, which reflect individual team performance, were extracted from the FTC Stats online database [14]. This rating represents the total score of a team across three phases of the game: autonomous (auto) mode, teleoperated (teleOp) mode, and the endgame.

While some evaluation scores rely on the collective performance of two teams in an alliance during a robot game, our analysis emphasizes individual team performance. The non-penalty OPR, which distinguishes a team's unique contribution to the game, more effectively aligns with the objectives of this research.

The auto mode lasts for 30 seconds, during which robots operate entirely autonomously, requiring no human intervention to complete predefined tasks outlined in the game manual. The teleOp mode spans two minutes, empowering two human drivers to control their robots in pursuit of various game-specific objectives. Finally, the endgame assesses the robot's performance in the match's concluding stage. Consequently, the more tasks a robot successfully completes across these phases, the higher the team's overall non-penalty OPR.

Assessment Methods

All quantitative measures in the surveys were evaluated using the mean and standard deviation, or displayed via histograms. Furthermore, survey results from regional, state, and world championships were compared to identify the key factors contributing to a team's growth. Due to varying numbers of responses at regional, state, and world level competitions, unpaired t-tests were conducted to assess statistical significance (p-value <0.05).

Results

Facts for States and World Championships

A total of five surveys were conducted: one at a Regional Championship during the 2023–2024 season (RC2024), two at State Championships in the 2022–2023 and 2023–2024 seasons (SC2023 and SC2024, respectively), and two at World Championships during the same seasons (WC2023 and WC2024, respectively).

To provide a more precise context for the survey results, Table 1 summarizes the number of teams that participated in the regional, state, and world championships where the surveys were conducted. Additionally, the average and standard deviation of non-penalty OPR scores for all teams at each event were calculated and presented in the format Avg ± Stdev.

Across both seasons, the average non-penalty OPR consistently increased from regional to state to world championships. This trend reflects how higher-performing teams progressed through the competition, with those advancing to higher levels typically gaining an additional month to refine and enhance their robots.

Table 1. Overview of number of teams, survey responses, and team performance across six FTC events during two consecutive seasons.

Event	Number of teams in the event	Number of survey responses	Non-penalty OPR (Avg ± Stdev)
RC2023	175	Not data collection	51.26 ± 33.02
SC2023	72	53	78.38 ± 29.06
WC2023	192	131	84.24 ± 28.85
RC2024	194	89	45.38 ± 34.85
SC2024	72	58	94.16 ± 34.53
WC2024	224	120	98.01 ± 38.84

A total of 194 teams participated in the 2023–2024 season, compared to 175 teams in the 2022–2023 season in central Texas region. This indicates growth in the FTC program in central Texas, with an increase of 19 teams.

Since FTC releases a new game manual each season, direct performance comparisons between seasons are invalid. However, within each season, team performance consistently improved from regional to state to world championships, reflecting the progression of higher-performing teams.

Notably, the Texas state championships exhibited performance levels comparable to those at the world championships in both seasons. The average non-penalty OPR was 78.38 ± 29.06 in the 2022–2023 season and 94.16 ± 34.53 in the 2023–2024 season for the Texas state championships, while the world championship OPR was 84.24 ± 28.85 in 2022–2023 and 98.01 ± 38.84 in 2023–2024. These results highlight the competitiveness of Texas in the FTC program.

Table 2. Quantified team attributes in regional, state, and world championships in 2 seasons.

Event	Team size (AVG±STD)	FTC experiences (years)	Percentage of school teams	Percentage of teams holding off-season meetings	Expenditure (USD$)
SC2023	9.9±3.64	2.28±1.15	74.07%	77.78%	N/A
WC2023	9.95±3.81	2.71± 1.2	49.24%	82.58%	18,846
RC2024	8.6±3.52	2.13±1.38	82.22%	67.78%	4,062
SC 2024	9.63 ± 4.10	2.43±1.02	70.00%	83.33%	9,710
WC2024	10.17 ± 3.77	2.54 ± 1.60	53.00%	89.26%	19,844

Outcomes of surveys

We analyzed five quantified team attributes: team size (number of team members), percentage of school-affiliated teams at each event, teams' FTC experience in years, percentage of teams holding off-season meetings, and average season expenditure, as summarized in Table 2.

The average team size remained consistent across the five events, indicating that team size does not significantly impact performance. Additionally, teams competing in the world championships had slightly more FTC experience on average than at the state and regional levels in both seasons with p-value <0.05. Table 2 presents the average expenditure, team size, and FTC experience in years. On average, an FTC team may need two to three years to grow and advance to the world championship, suggesting a potential timeframe for FTC coaches to strategically plan training and development to build a well-established FTC team.

Notably, the percentage of school-affiliated teams decreased significantly from regional to state to world championships in both seasons. This trend suggests that community-affiliated teams were more likely to advance to higher levels of competition.

Additionally, off-season engagement proved to be a critical factor in team success. The majority of teams that advanced to the world championships held off-season meetings (82.58% in the 2022–2023 season and 89.26% in the 2023–2024 season), underscoring the importance of off-season preparation in enhancing performance. Specifically, in WC2024, 98.2% of community-affiliated teams engaged in off-season activities, compared to 84.1% of school-affiliated teams, further emphasizing the impact of consistent practice and development outside of the regular season.

Lastly, team expenditures increased substantially from regional to state to world championships during the 2023–2024 season, with a statistically significant p-value <0.001, underscoring the strong financial burden for teams advancing to state and world-level competitions. Moreover, higher expenditures in state and world-level competitions suggest potential financial challenges for teams from underserved communities. Finally, no statistically significant differences were observed between the expenditures reported for WC2023 and WC2024.

Analysis of training on FTC

Twenty-seven different training topics were reported across the five surveyed events. Figure 1 and Figure 2 illustrate the most adopted trainings on technical and soft skills.

Training in Computer-Aided Design (CAD), odometry, and programming was extensively reported among teams competing at the world championships across both seasons. Furthermore, teams at the world championship level reported a higher frequency of engagement in a broader range of technical training—covering all seven key areas, including camera/image processing, computer numerical control (CNC), control systems, and encoder usage—than teams at state and regional competitions.

Similarly, teams at the world championships reported considerably greater participation in soft skill training, including documentation, presentation, collaboration, and safety training, compared to teams at the state and regional levels, as shown in Figure 2. Importantly, the number of teams engaging in soft skill training at the world championships was nearly double that of teams at the regional and state levels, underscoring the importance of well-rounded skill development for competitive success.

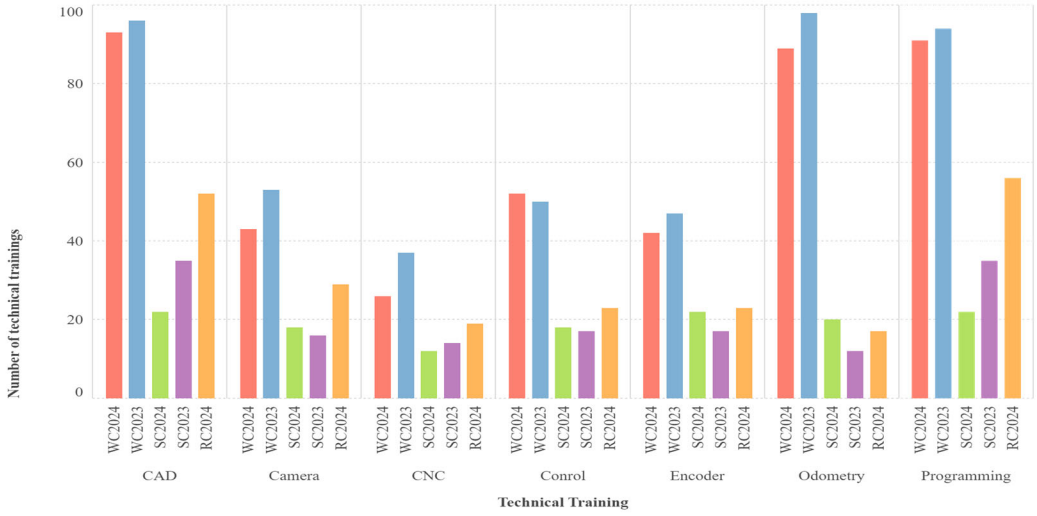

Figure 1. Seven widely adopted technical trainings reported at 5 events.

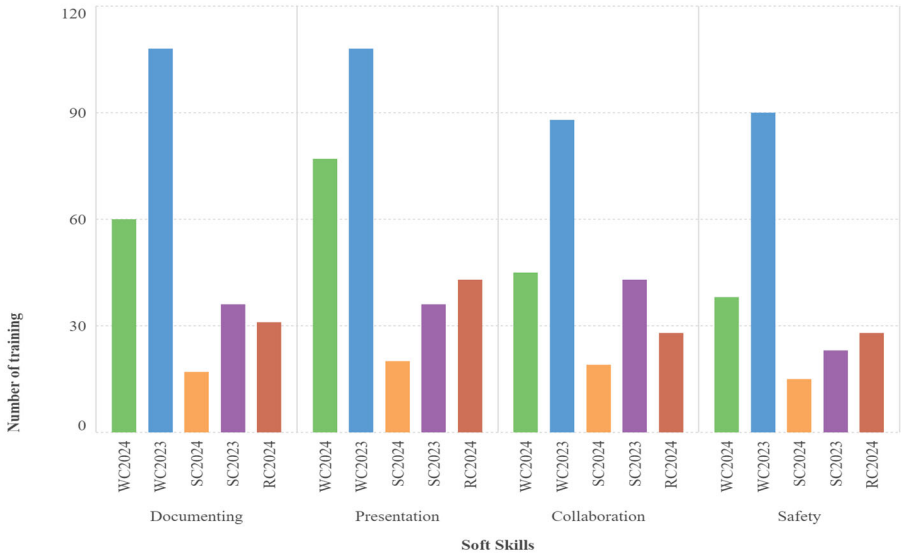

Figure 2. Four widely adopted trainings on soft skills reported at 5 events: WC2024, WC2023, SC2024, SC2023, and RC2024.

Our survey revealed that teams competing at the world championship level typically dedicate over 12 hours weekly to working on their robots and outreach activities. In contrast, teams at the regional level spend approximately 6–9 hours per week on these activities. Moreover, many teams advancing to the world championships reported spending over 30 hours per week during the final month preceding the competition, underscoring the rigorous preparation required at the highest level.

Given that the number of teams varied across events, a normalized percentage was calculated by determining the ratio of teams reporting each collaboration level to the total number of survey responses, as illustrated in Figure 3.

The survey categorized team collaboration into six levels: N/A, <25%, 26–50%, 51–75%, 76–90%, and >90% of tasks completed collaboratively within a team. The results indicate a high level of collaboration among FTC teams, with 78.3% (WC2024), 88.1% (SC2024), 79.8% (RC2024), 86.2% (WC2023), and 92.5% (SC2023) of teams reporting that at least 50% of their tasks were completed collaboratively. These findings underscore the strong emphasis on teamwork within FTC competitions.

For SQ12, the most frequently raised concern among surveyed teams at WC2024 was time management, particularly regarding how to effectively coordinate team members to collaborate on tasks. This challenge is especially significant given that most highly competitive FTC teams at WC2024 invest 9–12 hours per week in robot development. To gain deeper insights, we will include this question in future surveys to collect strategies and best practices from FTC teams.

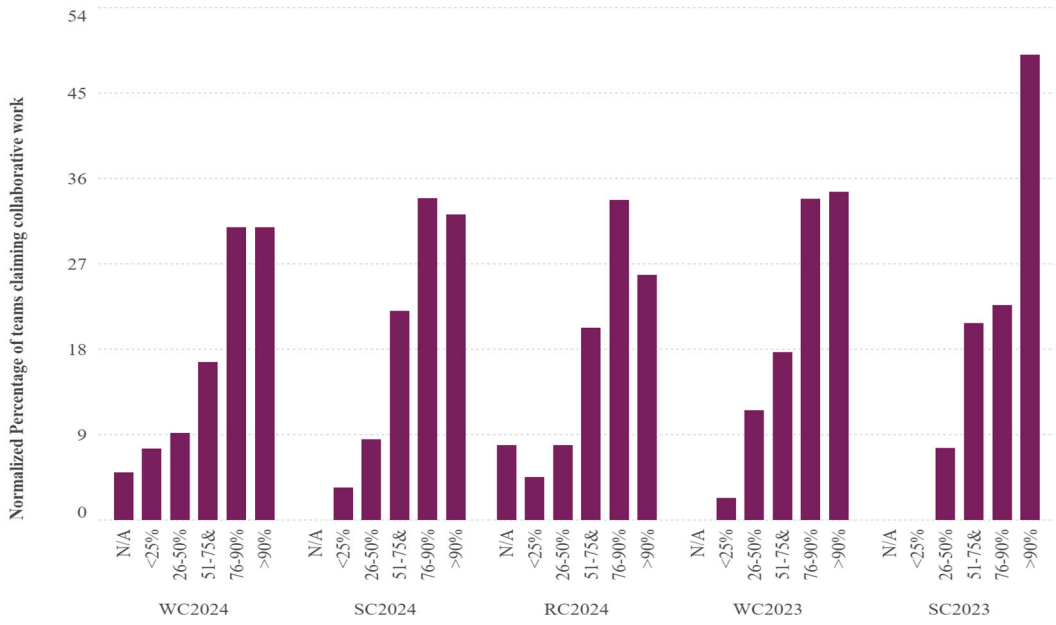

Figure 3. Percentage of collaboration levels reported by teams participating the surveys at 5 events: WC2024, WC2023, SC2024, SC2023, and RC2024.

Discussion

This study presents the first quantitative analysis of team attributes in FTC robotics competitions. We evaluated team performance at the regional, state, and world level competitions, quantifying improvements observed at each stage. While it is widely recognized that teams competing at the world level generally achieve higher performance, our analysis provides a data-driven comparison of performance differences across competition levels. By visualizing these trends, this study aims to help teams set clear goals for future development and improvement.

It is interesting to see that more community-affiliated teams advanced to state and world championships, along with their greater participation in off-season activities. A possible explanation is that the administration of school-affiliated teams often pauses due to the limited availability of coaches and restricted access to school resources during break periods. Additionally, funding can be restrictive in school-affiliated teams due to school district purchasing rules. In contrast, community-affiliated teams do not face these limitations.

Additionally, our survey reveals significant differences in training between teams that advanced to the world championships and those that did not. Notably, training in programming, CAD, encoders, odometry, control systems, and camera/image processing was more prevalent among teams advanced to world championships. This underscores the importance of off-season skill development, particularly for rookie teams, as acquiring these technical skills can significantly improve their chances of advancement.

Besides team commitment and training, the expenses incurred by FTC teams advancing to world championships are significantly higher than those reported by teams in regional and state championships. Although most teams collect team fees, there is a strong need for fundraising. This is especially important for team administrators and coaches to establish a well-structured plan at the beginning of the season. Experienced FTC teams may use spare parts from prior seasons, while rookie teams often face higher-than-expected expenses since they lack spare parts from previous seasons.

It is well understood that increased training and effort contribute to team success, but how much effort per week? How long does it take for an FTC team to mature? As the first large-scale survey examining FTC teams' efforts and perspectives, our study identifies 1) the essential skills such as programming, odometry, control, image processing, documentation, and presentation, 2) level of commitment (9 -12 hours per week) needed for advancement to the world championship, 3) possible expenditures for a season with different levels of advancement as shown in Table 2, and 4) expected mature time (2-3 years) for an FTC team to advance to world level championship. These findings offer valuable insights for FTC coaches, mentors, and team captains, assisting them in structuring effective training programs and optimizing time allocation.

Over the past 35 years, millions of students in grades 7–12 have participated in FTC competitions, making the FTC community a key driver in inspiring young minds to pursue STEM fields and preparing future robotics professionals from an early age. Our survey

highlights FTC teams' substantial commitment to robot building and outreach activities. Teams advancing to the world championships typically invest 9–12 hours per week from early September to late April. If measured in academic terms, this commitment exceeds the workload of a three-credit senior or capstone project. Even though most FTC teams are school-affiliated, robotics competitions are rarely integrated into formal coursework. School administrators have made limited efforts to recognize FTC participation as part of senior projects or capstone experiences. This gap presents an opportunity for educators to enhance robotics education by formally incorporating FTC involvement into academic curricula.

Conclusion

The insights gained from this study provide valuable guidance on FTC team coaching and management, benefiting FTC coaches, team members, and event coordinators. Our findings suggest several key factors contributing to the growth and advancement of FTC teams to world-level competitions, including (1) consistent participation in off-season activities, (2) specialized technical training in programming, odometry, CAD, camera/image processing, and control, and (3) structured soft skills training in documentation and presentation. Notably, community-affiliated teams may have an advantage in these areas, as a greater number of them have advanced to world championships. By offering a data-driven perspective on training strategies, time allocation, and task assignments, these findings can help teams refine their preparation, enhance their competitiveness, and improve overall program effectiveness.

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