Space Teams STEM Competition: Outcomes and Efficacy

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Space Teams is a six-day long STEM competition where elementary through high school students around the world compete in designing the most efficient interplanetary mission using a high-fidelity spaceflight simulator, SpaceCRAFT. A study was conducted to gauge how greater engagement in the program affected students' understanding of the engineering design process, STEM identity and self-efficacy, interest in STEM, and overall understanding of the importance of exploration. In addition to time spent in the program, engineering analysis data over the students' designs, survey responses and quiz scores were recorded to investigate relationships between engagement in the program, positive feedback and higher performance. After data analysis, it was concluded that greater engagement in the Space Teams competition resulted in greater understanding of the engineering design process, positive attitudes towards space science and engineering, significantly greater STEM identity and self-efficacy, and an increased understanding of the importance of exploration.

I. Nomenclature

ANOVA	=	Analysis of Variance
ATIS	=	Assessment Tools in Informal STEM
ESSA	=	Every Student Succeeds Act
STEM	=	Science, Technology, Engineering and Math

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II. Introduction

Space exploration has always been at the pinnacle of human inspiration, providing universal motivation to further the advancement of spaceflight technology and space science. Even with recent innovations, spaceflight remains an incredibly difficult challenge with a high cost, which reduces the accessibility for engagement outside of the aerospace industry. However, space system design and mission planning have become more accessible with the use of increasingly realistic simulation tools. The improvements in simulation technology have created an opportunity to efficiently teach aerospace topics and engineering design to children in elementary, middle and high school by harnessing the inspirational nature of spaceflight and providing a platform for which the students can interactively learn in a virtual, realistic environment. The currently rated ESSA Level 4 STEM program, Space Teams, aims to utilize this technology by providing unique, realistic and immersive learning experiences to bolster STEM education.

Space Teams is a six-day international STEM program in which students, from elementary through high school, are given an incredible opportunity to virtually participate in space exploration themselves utilizing a high-fidelity space simulation platform called SpaceCRAFT. SpaceCRAFT is currently used for NASA projects, ongoing research, Space Teams competitions, and space industry applications. As such, the students' experience with Space Teams is incredibly accurate, both in terms of the physics/engineering aspects and realism of the spaceflight experience. Using SpaceCRAFT software, students form mission teams, design interplanetary vehicles, navigate to another planet, land their vehicles, build planetary habitats, and explore a new planet to find resources necessary to sustain human life.

Each day of the program focuses on a new module of the mission, shown in Figure 1. For each module, students are given a lesson, a quiz, a tutorial, a special guest lecture, and a daily activity. Subject matter experts including astronauts, scientists, and engineers are directly involved in instructing students as they compete with other teams in their current design mission. The daily lessons and quizzes provide the students with knowledge needed to design their long duration spaceflight mission, with topics including planetary science, spacecraft systems, orbital mechanics and robotic exploration. These lessons bring all aspects of space exploration and the engineering design process to an understandable level for young students, who learn by doing and creating with these concepts themselves. In order to have a competitive design, students must follow the engineering design process and incorporate new principles and critical thinking skills while effectively working together within their teams. The overall goal of their design is to achieve long term sustainability in a new planetary environment by achieving a balance between resources, mass, and other factors. Students are encouraged to iteratively test and update their designs throughout the program while they compete for the highest scores against other teams. The outcome of this program is to provide a foundation of confidence and knowledge that will inspire young explorers to continue pursuing STEM subjects and ultimately enable them to join the international community of scientists and engineers working on the advancement and exploration of space.

This study aims to measure the efficacy of the Space Teams program with respect to STEM engagement, STEM identity and understanding of space science and the engineering design process. This will be done through the acquisition of participation and success data during the program, as well as retrospective pre-post questionnaire data. The proven outcomes from the proposed gathering and analysis of data may qualify Space Teams to be considered an ESSA Level 3 program.

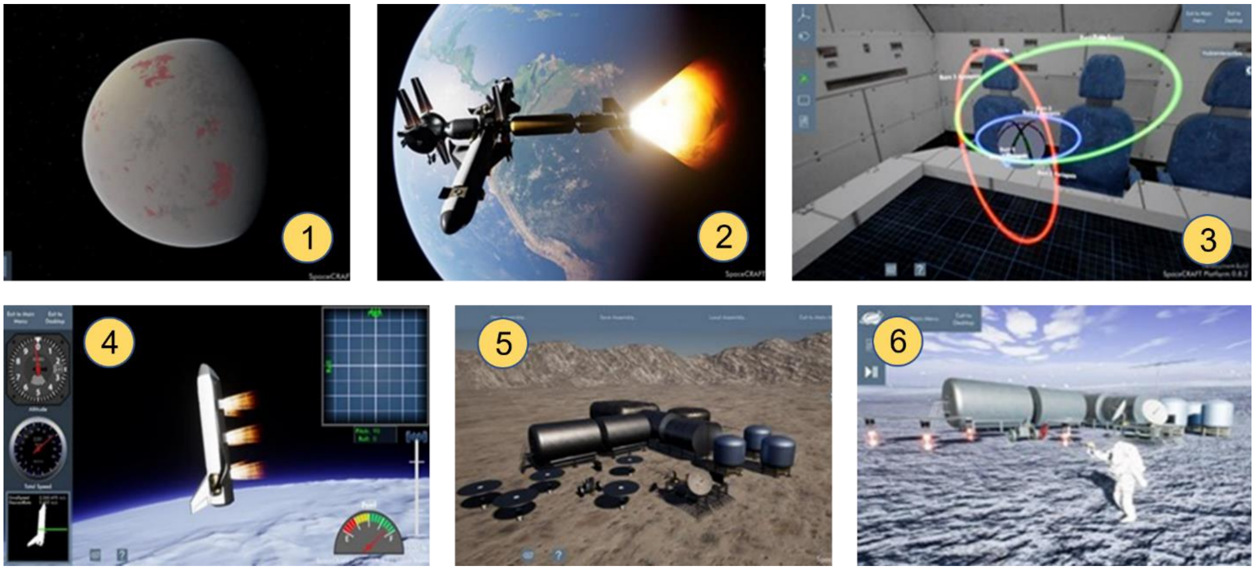


Figure 1: The Modules for Space Teams include: (1) Planetary Science and Exploration, (2) Spacecraft Design, (3) Orbital Mechanics and Remote Sensing, (4) Atmospheric Entry, Descent and Landing, (5) Habitat Construction, and (6) Surface Operations.

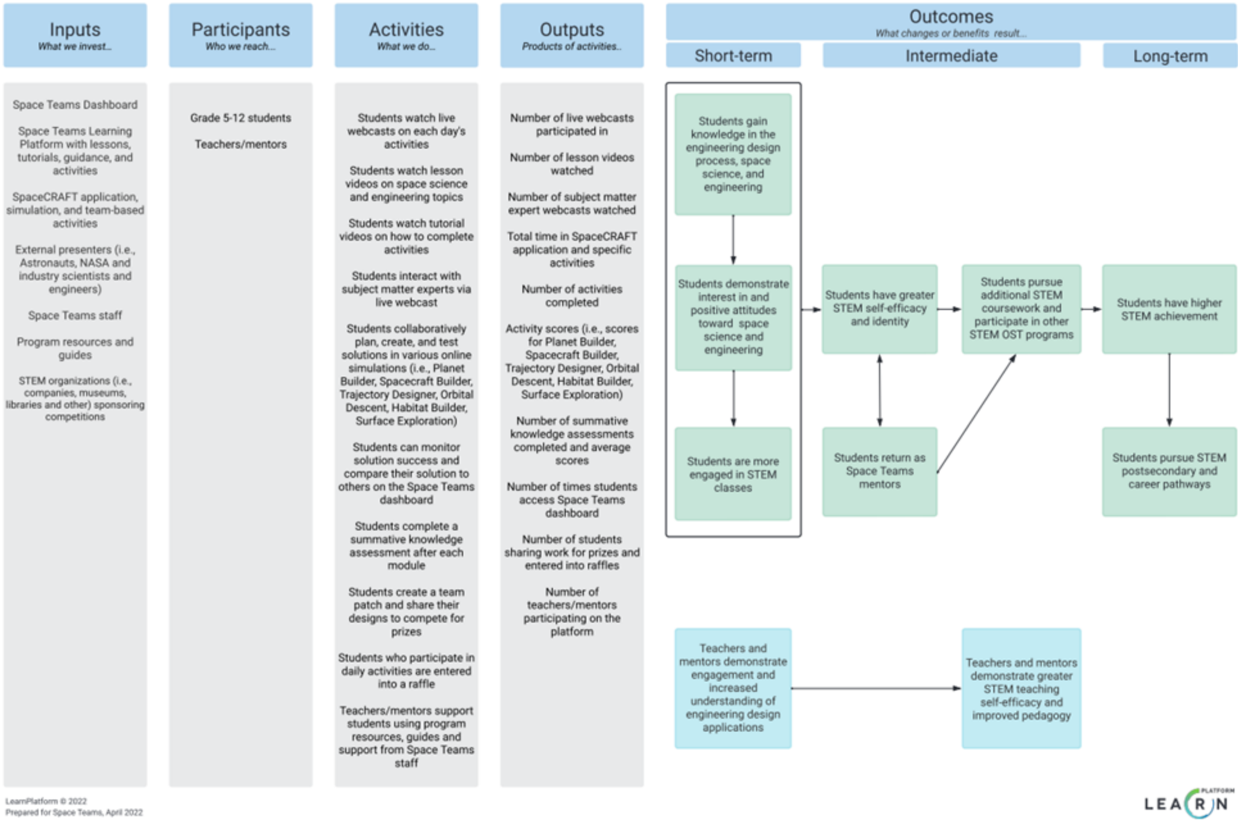
III. Methods

The measurements and quantifiable results of this study are based on a previously designed logic model for the Space Teams program. This model was developed by LearnPlatform to identify how the program can impact learners. The logic model translates inputs into measurable activities that lead to expected results. Table 1 contains the five core components needed of a logic model (inputs, participants, activities, outputs, and outcomes) and was used to produce the more complex and complete logic model shown in Table 2.

Table 1: Logic Model Component Descriptions

Component	Description	More information
Inputs	What we invest	What resources are invested and/or required for your product to function effectively in real schools?
Participants	Who we reach	Who receives the product or intervention? Who are the key users?
Activities	What we do	What do you do with the resources identified in Inputs? What are the core/essential components of your program? What are you delivering to help students/teachers achieve the program outcomes you identify?
Outputs	Products of activities	What are numeric indicators of activities? (e.g., key performance indicators; allows for examining program implementation)
Outcomes	Short-term, intermediate, long-term	Short-term outcomes are changes in awareness, knowledge, skills, attitudes, and aspirations. Intermediate outcomes are changes in behaviors or actions. Long-term outcomes are ultimate impacts or changes in social, economic, civil, or environmental conditions.

Table 2: Space Teams Logic Model



The **inputs** of the Space Teams logic model include resources such as the high-fidelity SpaceCRAFT software, Space Teams dashboard and learning platform (websites students use to access the daily modules), as well as personnel including the Space Teams staff, presenters and more. As shown in the model diagram (Table 2), **participants** then interact with these inputs. These participants include the students (Grade 5-12) that compete in the Space Teams program, as well as the teachers and mentors that guide the students in the competition. The participants use the resources displayed in the inputs of the logic model to engage with Space Teams via **activities**. These activities include lesson videos on space science and engineering topics, daily live webcasts, tutorial videos, and other ways of interacting with the program. All activities listed above in the logic model are specifically made with the participants and inputs in mind so that there can be quantifiable results known as **outputs**. The outputs of the Space Teams logic model vary from logistics, such as the information of the participants, to the data of scores versus their total time of engagement throughout various aspects of the program. This study focused on the quantifiable and analyzable outputs in order to validate the outcomes, with the outcomes representing the study's investigative goals.

This study aims to answer the four questions below by utilizing the quantifiable outputs described in the logic model to validate the established outcomes:

1) Does the degree of engagement in Space Teams correlate with an understanding of the engineering design process?
2) Does engagement in Space Teams increase interest in and positive attitudes towards space science and engineering?
3) Does engagement in Space Teams increase STEM identity and self-efficacy?
4) Does engagement in Space Teams increase understanding of the importance of exploration?

The short-term and intermediate affective outcomes were investigated using retrospective pre-post surveys in which students subjectively rated themselves. The retrospective pre-post design is effective for interventions with a duration of less than three weeks since it eliminates some of the response shift bias that can impact traditional pre-post designs. Quantitative data collection included a pre-post survey measuring changes in students' attitudes towards space science, engagement in STEM activities, STEM efficacy, self-efficacy, STEM identity, and students' intent to pursue additional STEM activities and informal STEM opportunities. Qualitative data was collected via open-ended survey questions aimed at students to determine the most and least effective aspects of their experiences in the program. The surveys were adapted from previously validated instruments measuring similar constructs with secondary students. These previously validated measurement methods, such as the Likert scale, come from a tool named Assessment Tools in Informal STEM (ATIS) which is widely used by facilitators and educators. Student participation metrics, including number of sessions completed, were collected via the Space Teams platform. Daily lesson quiz responses and daily challenge scores were utilized to determine the extent to which students were mastering module objectives. Data analysis utilized analysis of variance (ANOVA) to determine the statistical significance of the study findings. Table 3 coordinates the chosen evaluation questions with data sources and corresponding analysis methods.

Table 3. Evaluation Questions, Data Sources, and Analysis Part 1

Evaluation Questions	**Data Sources & Inputs**	**Data Analysis Method**
Q1. Does the degree of engagement in Space Teams correlate with an understanding of the engineering design process?	• The amount of time students spent in the space team program • Quiz results • Activity Score results • Retrospective pre-post student survey (items adopted/adapted from Students' Perception and Attitude towards Space Science Survey [Majid et al, 2015])	● Descriptive statistics of closed-ended survey responses, quiz scores and activity scores ● Between groups repeated measures analysis of variance (ANOVA) across survey time points and student factors, such as grade level, ethnicity, etc.
Q2. Does engagement in Space Teams increase interest in and positive attitudes towards space science and engineering?	Retrospective pre-post student survey (items adopted/adapted from the Math and Science Engagement Scales [Wang et al, 2016])	• Descriptive statistics of closed-ended survey responses • Inductive analysis of emergent themes in open-ended survey questions and interviews
Q3. Does engagement in Space Teams increase STEM identity and self-efficacy?	Retrospective pre-post student survey (items adopted/adapted from the Student Attitudes Toward STEM (S-STEM) Survey [Friday Institute for Educational Innovation, 2012])	• Descriptive statistics of closed-ended survey responses • Inductive analysis of emergent themes in open-ended survey questions and interviews
Q4. Does engagement in Space Teams increase understanding of the importance of exploration?	Retrospective pre-post student survey (items adopted/adapted from the STEM Identity Survey [Grimalt-Alvaro et al, 2021])	• Descriptive statistics of closed-ended survey responses and quiz scores • Inductive analysis of emergent themes in open-ended survey questions and interviews

As mentioned, student participation metrics, activity scores and quiz scores were collected via the Space Teams platform. Back-end server computations allow for telemetry readings that output all these data values. The amount of data required the use of Python programming to successfully determine the extent to which students mastered module objectives. Therefore, the Python program Pandas was used to make valuable data frames which output the parameters discussed previously, such as time spent on activities and scores for each student that participated. Data analysis utilized analysis of variance (ANOVA) to determine the statistical significance of the study findings. To run the ANOVA assessment, R code was implemented with an alpha value (also known as significance criteria) of 0.05, as it is the standard significance criteria for most research. Generalized linear regression models were used in the process of displaying data visuals. To determine the statistical significance of the results, t-tests were utilized.

IV. Results

To ensure the data was statistically significant, ANOVA was conducted over the collected data and how each variable (listed in Table 5) affected the overall scores. The ANOVA and t-test results are summarized in Table 5. The ANOVA results determine whether or not the null hypothesis is accepted as true, where the null hypothesis states: There is no effect on overall score from total time spent or school league. To prove or disprove the null hypothesis, the p-value is compared to the alpha value. For this analysis, a significance criteria of alpha = 0.05 was used.

Table 5: ANOVA Results Table: Overall Score

Variable	F value	p-value
Total Team Time Spent in Activity	23.446	3.93e-05
School League (Elementary, Middle or High School)	0.225	0.800
Interaction between Total Team Time & School League	0.143	0.708

From Table 5, the total activity scores were used as the dependent variable. Total time spent per team, age range of teams, and total time spent per team per age group were the independent variables. To reject the null hypothesis, the p-value needs to be less than the alpha value. By looking at the p-values compared to the significance criteria, the only statistically significant variable was “total time spent per team,” as the p-value of team time was less than 0.05. For “the total time spent,” the null hypothesis was rejected and now states: There is an effect on overall score from the total time spent. The school league was not found to have a statistically significant impact on overall team score due to a p-value less than 0.05. In addition, there was no significant interaction effects between total team time and school league. Therefore, the ANOVA results indicate that the overall score in the program was significantly impacted by the amount of time students spent in the activities, but the school league did not have an impact on the likelihood of a higher score.

The first activity was designed to allow students to get acquainted with the interface and controls of the software, so no score was taken for this activity. The following five activities had a possible score of 100 points. Due to the sixth activity having a bug that enabled some teams, but not all, to have early access, the sixth activity score was removed from the overall counts to allow for a fair competition and data record. Therefore, the highest possible overall activity score was 400 points.

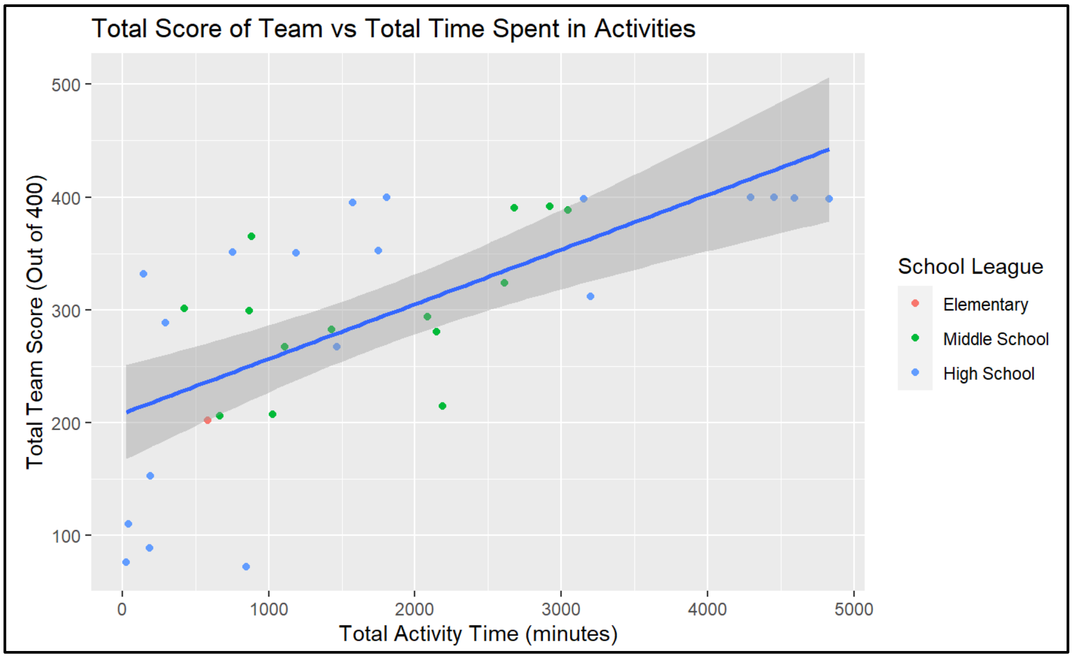


Figure 2: Total Scores of Teams Based on School League

As far as time, the students had 6 days to complete the competition. Assuming students spent 10 hours a day sleeping or eating and 2 hours on the lectures and quizzes, the estimated maximum number of minutes they could spend on the competition was 4320 minutes. Depending on the country, some students were also attending class during the week of the competition, reducing their maximum available time. The interactive program with online webcasts was scheduled for 4 hours per day, but teams had the opportunity to work outside of these hours. The "Total Activity Time" demonstrated in Figure 2 above represents the total active minutes a particular team spent working in the SpaceCRAFT application. Overall, there was a positive correlation between the amount of time students spent on activities and their scores.

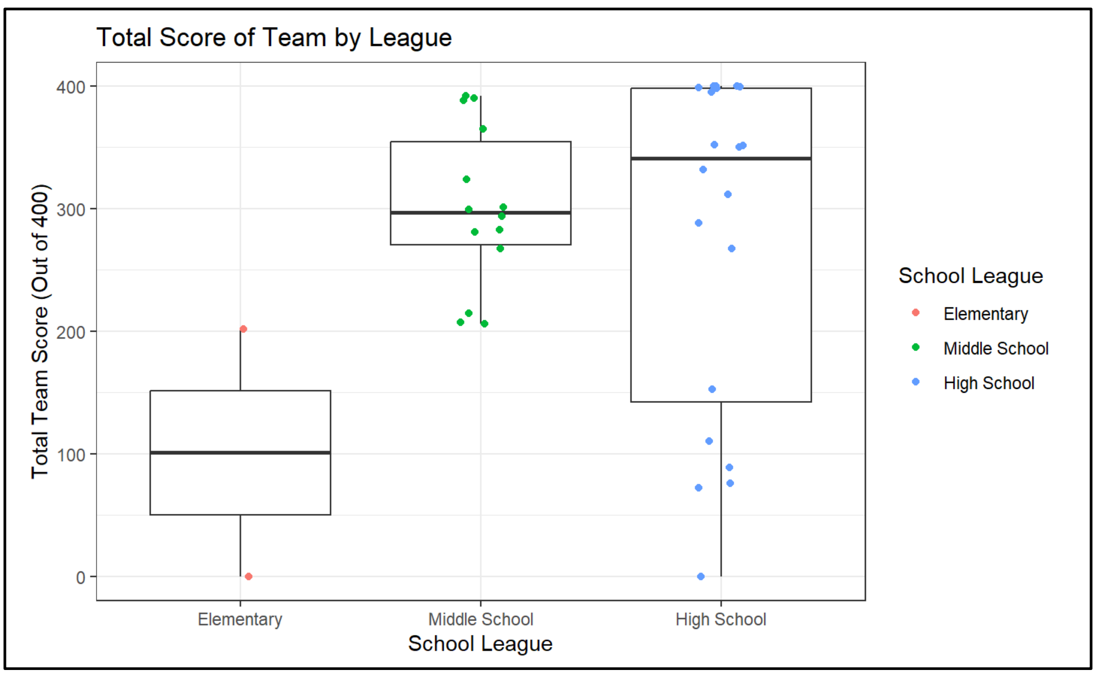


Figure 3: Total Scores of Teams vs Total Activity Time

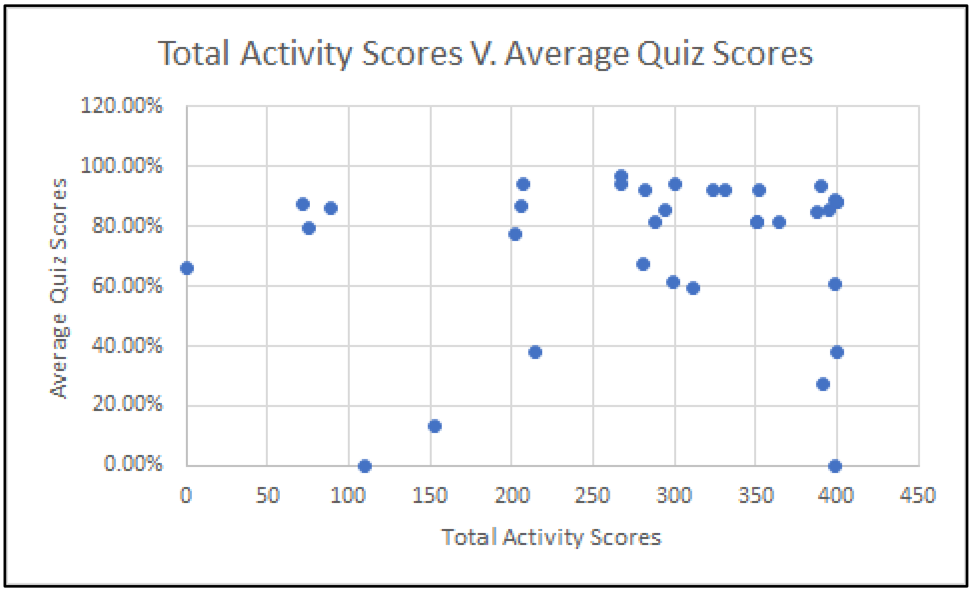


Figure 4: Total Activity Scores versus Average Quiz Scores

As shown in Figure 3, the breakdown between different age groups indicates that the middle school and high school teams were relatively evenly competitive. The bounding boxes in Figure 3 indicate the 25th percentile (bottom of the box) to the 75th percentile (top of the box), where the bolded black lines represent the average score. High school students had an average overall activity score of 322.1 (80.5%) while the middle school teams had an overall activity score of 287.7 (72%). While high school teams did have higher average scores, the lowest scores for middle school teams was still well above the 25th percentile scores of the high school teams. In addition, the average of the top three high school team scores were only 2.45% higher than the average of the top three middle school team scores. The amount of elementary school participants was not significant enough to truly indicate their performance in this competition. However, from the available data, it appears that the elementary school students had significantly worse scores, with their highest score being equivalent to the lowest middle school scores. In Figure 4, the total sum of activity scores were compared to the average quiz scores for each team. The variety in quiz scores was relatively low compared to the variety in activity scores, with an average quiz score of 72.87% across all age groups and an average activity score of 264.79 (66.20%). Overall, the overall scores and quiz results suggest that both middle school and high school students can perform competitively with each other in the Space Teams program.

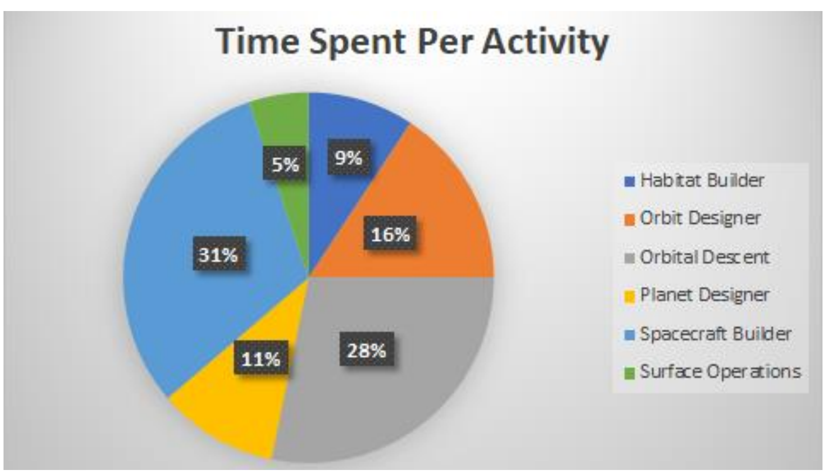


Figure 5: Time Spent Per Activity

When users were logged in and active in the SpaceCRAFT application, their session time was recorded to measure how much time was spent in each different activity. Participants spent roughly 60% of their time in the Spacecraft Builder and Orbital Descent activities, with the rest of their time divided between the other four activities

(Figure 5). The software bug in the Surface Operations activity (sixth activity) resulted in some teams having early access and other teams were locked out, ultimately resulting in a removal of that activity from the competition scoring. Therefore, the data collected for time spent in that activity came from the teams that did have early access through the bug in the software.

At the conclusion of the program, students were asked a series of survey questions to reflect on their viewpoints before and after having participated in Space Teams. The students were asked to rate their agreement with the questions on a scale from one to five, with five being the most agreeable. Ninety-one responses were recorded for these survey questions. The questions asked are as follows:

1) Before participating in Space Teams, I was already interested in STEM-related clubs and/or extracurricular activities.
2) After participating in Space Teams, I am interested in STEM-related clubs and/or extracurricular activities.
3) Before participating in Space Teams, I was already considering a career in Science, Technology, Engineering, or Math (STEM).
4) After participating in Space Teams, I am considering a career in Science, Technology, Engineering, or Math (STEM).
5) Before participating in Space Teams, I intended to get a college degree in Science, Technology, Engineering, or Math (STEM).
6) After participating in Space Teams, I intend to get a college degree in Science, Technology, Engineering, or Math (STEM).
7) Before participating in Space Teams, I could already see myself working as a STEM professional.
8) After participating in Space Teams, I can see myself working as a STEM professional.
9) Before participating in Space Teams, I knew I would like to have a career in STEM.
10) After participating in Space Teams, I would like to have a career in STEM.

Table 6: t-test Results Table: Overall Score

Before/After Statement	t-value	Degrees of Freedom	Mean Difference	p-value
1	-3.959	89	0.356	7.574e-05
2	-4.324	89	0.378	1.997e-05
3	-4.063	89	0.289	5.202e-05
4	-6.811	89	0.722	5.502e-10
5	-5.326	89	0.478	3.736e-07

In order to determine if there was a statistically significant increase in the ratings of the scores from before the program versus after the program, a paired t-test was performed for each pair of before/after survey questions. The results of these t-tests are reported in Table 6, as well as the degrees of freedom for each test and the mean difference in response for each pair of survey questions. For this analysis, the null hypothesis states: Participation in Space Teams has no effect on the students' interest and perception of the STEM field. The significance criteria for these tests was alpha = 0.05, where the null hypothesis is rejected in instances where the p-values are lower than the alpha value. Given that every t-test produced a p-value that is much less than 0.05, it can be concluded that Space Teams as a program had a statistically significant impact on the students' interest and perception of the STEM field.

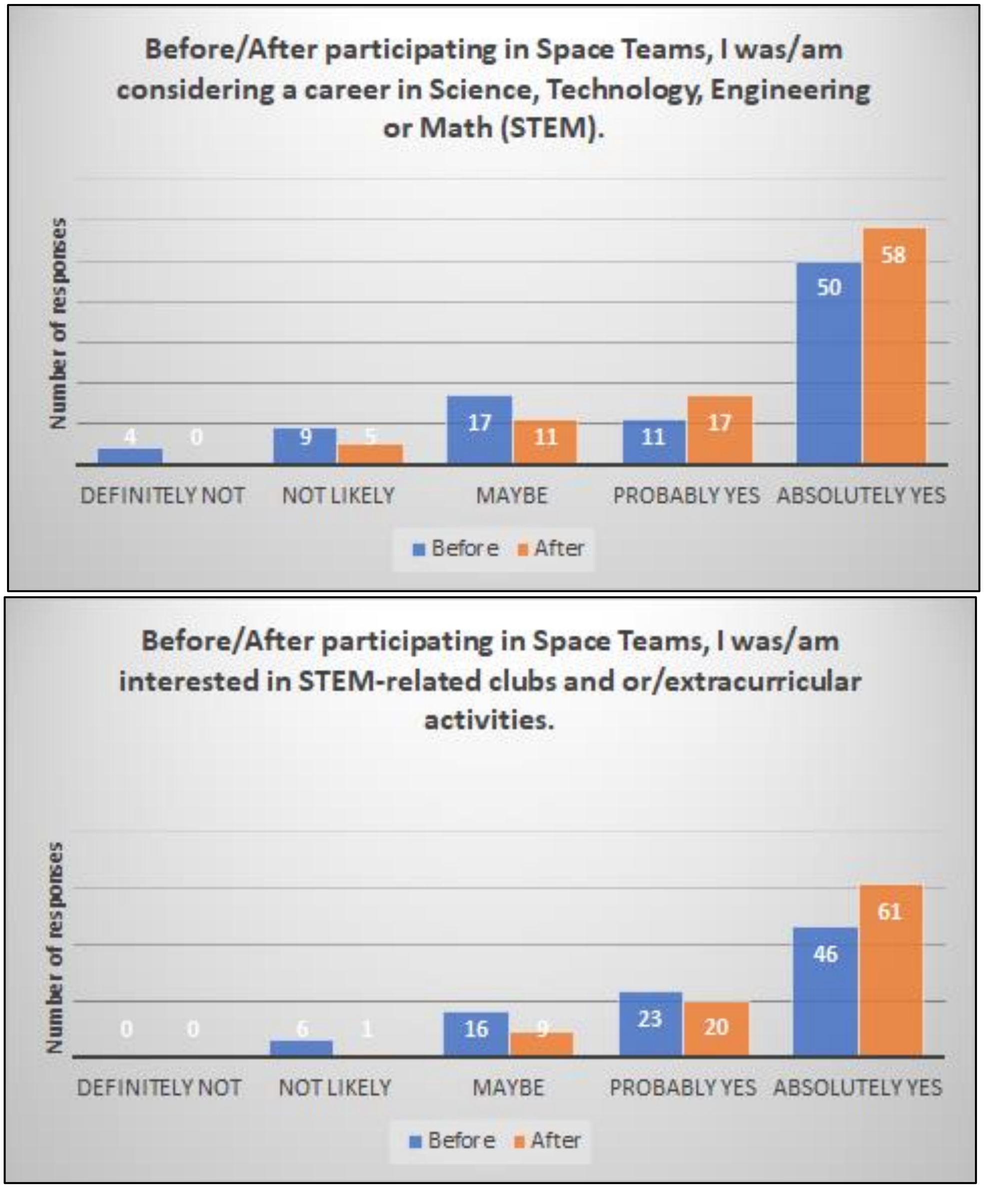


Figure 6: Post-Retrospective Survey Responses

As shown in Figure 6, there was a tendency for participants to have an increased outlook on STEM. Positive answers such as "probably yes" and "absolutely yes" see increases from before to after ranging from 13.04% to 47.82% respectively. In addition, students collectively gave positive responses regarding their interaction with Space Teams and its ability to encourage self-efficacy, STEM skills and awareness (Figures 7 and 8). Self-efficacy is the individual's own belief in their abilities to succeed in or accomplish specific goals. To help build self-efficacy, in addition to providing difficult STEM problems, Space Teams exposes students to real-world issues, presented by various STEM field experts during each day's guest speaker presentation. These experts provide students with insight into how they approach real-world problems, giving the students opportunities to apply those lessons learned to their current designs in the competition.

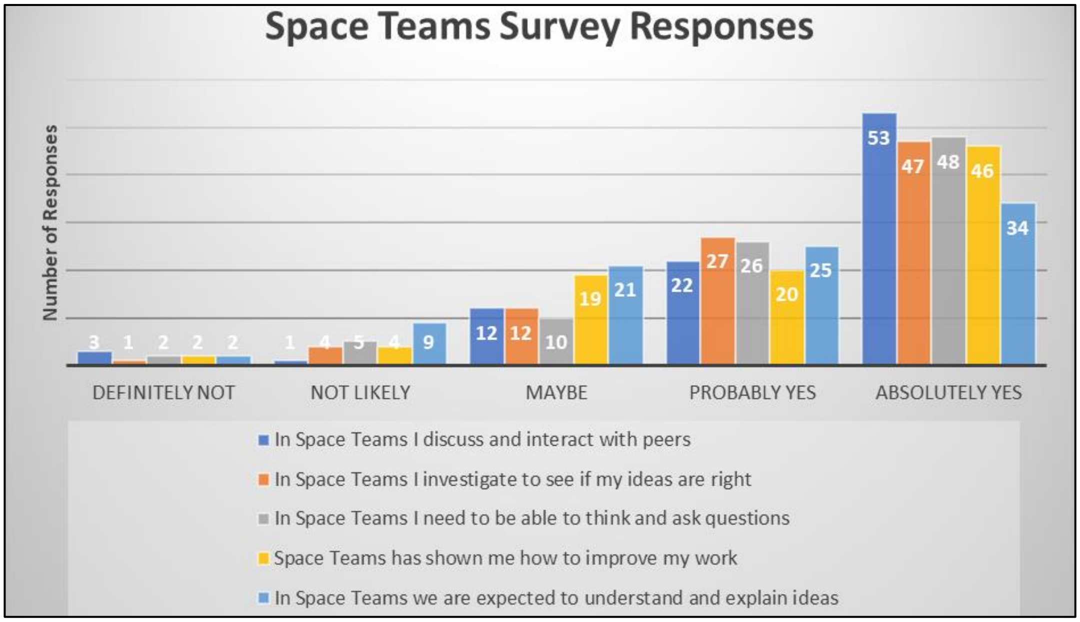


Figure 7: Space Teams Survey Responses Likert Scale Part 1

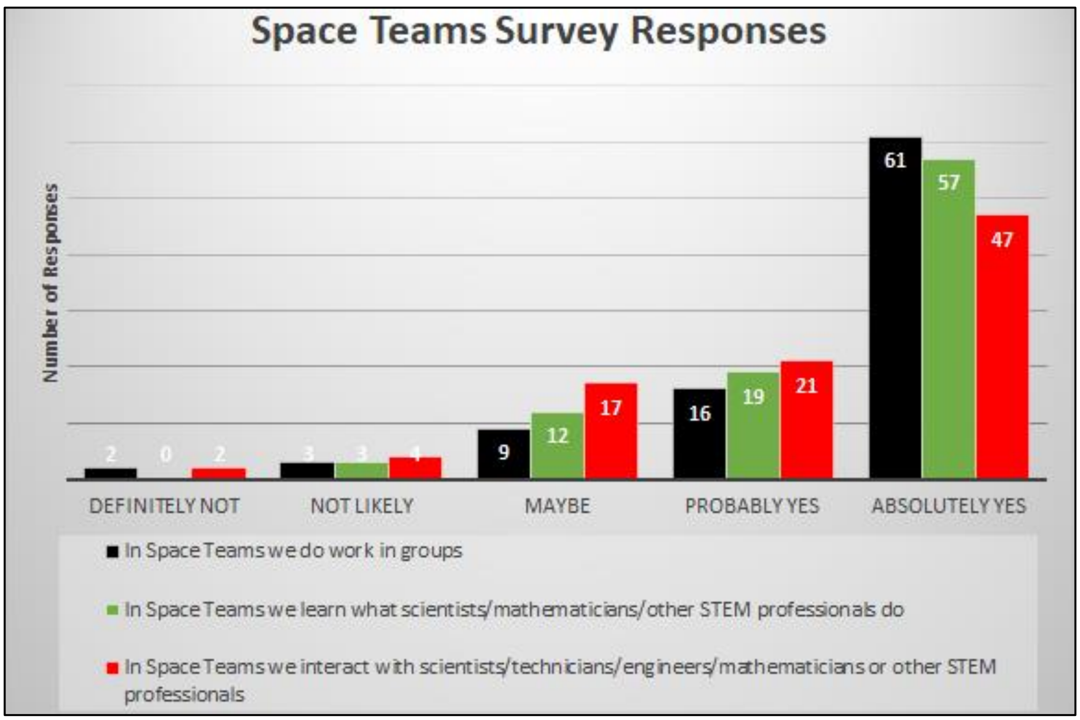


Figure 8: Space Teams Survey Responses Likert Scale Part 2

V. Discussion

A. Increased Understanding of the Engineering Design Process

To interactively teach the full concept of the engineering design process in a manageable way for different age groups, different components of the process had to be taught throughout both the daily lectures and the daily activities. The overall competition required students to design a mission to another planet. Therefore, to complete the competition, the students had to demonstrate a general understanding of the engineering design process. Analyzing the quiz responses alongside the overall activity scores, an average of 61.43% of the participants accomplished a score higher than 300, or 75% of the possible points. Overall, high school students had a higher score ceiling as well as a lower one making their average scores end up lower than the more consistent middle school competitors. Since a majority of the students in the competition were able to score 75% or more of the possible points with their missions designs, and time spent directly correlated with the scores, it can be concluded that Space Teams engagement results in a greater understanding of the engineering design process.

While the participants were prompted to take a module quiz at the completion of each daily lecture, they were not forced to submit a quiz score before being able to work on the next part of the competition. Some teams also seemed to take the quizzes as a group instead of individually. For future competitions, a control should be implemented to require individual quiz scores to be submitted before being able to access the daily activity to better understand how each individual is impacted by Space Teams. In addition, instead of focusing on overall scores, individual participant scores per activity and the number of submissions should be recorded in order to better evaluate each individual's understanding of the engineering design process.

B. Increased Interest In and Positive Attitudes Towards Space Science and Engineering

Students were given pre- and post- survey questions to gauge their interest and general attitudes towards space science and engineering. The post-retrospective survey results displayed a drastic positive change in student responses when prompted if they could see themselves working as a STEM professional. The changes in responses after participating in the competition suggests that exposure to Space Teams resulted in much more positive attitudes towards working with space science and engineering. In addition, compared to pre survey responses, 24.59% more students indicated they would absolutely like to participate in more extracurricular activities relating to engineering after completing the Space Teams program. Similarly, the net positive increase in space science outlook can be seen as post-competition students tended to now see themselves pursuing STEM as a future profession.

C. Increased STEM Identity and Self-efficacy

While a majority of the scores prove that the students have the capacity to solve difficult problems, the study also wanted to gauge their self-efficacy for solving those problems. This self-efficacy must show that they have been given the capacity to solve difficult problems. Based on proven ATIS questions, the survey asked the students if the program gave them the skills required to perform well in the STEM field. These skills, which are components of self-efficacy, include: good communication, good collaboration, and critical thinking. As seen in Figures 7 and 8, the students were given eight statements which reflect the components of self-efficacy. For all eight statements, students highly agreed that Space Teams successfully encouraged the mentioned skills. Students indicated that Space Teams encouraged them to think critically and collaboratively, which are skills required for them to be considered to have self-efficacy in space science and STEM related fields. In addition, students reported that they could see themselves working in STEM fields for professions later in life, suggesting they feel confident they belong in the STEM community.

D. Increased Understanding of the Importance of Exploration

Throughout the competition, students were prompted with many different scenarios to demonstrate the vast possibilities in how space exploration can advance current understandings and technology. These scenarios were talked about throughout the week and understanding of such matters is reflected in the final quiz scores. The overall final quiz average for all competitors across the three leagues was 72.87%, meaning that the majority of students were successful at understanding the importance of exploration. Considering that 86.8% of competitors responded in the survey that they had not participated in a program like Space Teams before, it can be concluded that the majority of these students gained a greater understanding of space science after having been first exposed to it in the Space Teams program.

VI. Conclusion

A research study was conducted to assess the outcomes and efficacy of student participation in a Space Teams STEM Competition. The students were asked to design an interplanetary mission using the SpaceCRAFT high-fidelity spaceflight simulation software. Engineering analysis was conducted over the students' designs and presented as feedback on a point scale. In addition, students were given quizzes to measure their understanding of space science and engineering concepts, as well as subjective pre- and post- competition surveys to gauge their attitudes and opinions over STEM activities. Through a combination of the collected qualitative and quantitative data, it was concluded that engagement in Space Teams resulted in an increased understanding of the engineering design process, greater interest in and positive attitudes towards space science and engineering, improved STEM identity and self-efficacy, and a greater understanding of the importance of exploration.

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