Impacts of a Pre-college STEM Outreach Program over Time (Evaluation)

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Introduction

A skilled STEM workforce is critical to maintaining the competitiveness of the U.S. in today's global economy. STEM job opportunities have grown faster than non-STEM counterparts since 2010, and employment in many STEM occupations is projected to grow [1]. Recently, many pre-college programs have been developed and implemented to increase high school students' interest in science, technology, engineering, and mathematics (STEM). Plentiful prior studies documented the positive impacts of such outreach efforts [2], [3], [4], [5], and [6], but how students' evaluations change during the program remained an unanswered question. This paper examines the incremental impacts of a pre-college STEM outreach program using three longitudinal surveys – opening, mid-program, and end-of-program surveys. Findings demonstrate how students' self-evaluations and perspectives on STEM college education change over time while attending a summer program, which will help educators and outreach project directors better design and implement such programs.

National Summer Transportation Institute (NSTI) is one of the Federal Highway Administration's (FHWA) educational initiatives. It is to "promote the Science, Technology, Engineering and Math (STEM) disciplines in transportation-education and career opportunities among middle and high school students, including at-risk youth." [7] The NSTI program presented in this paper was hosted by Central Connecticut State University. In 2013, when this program was first initiated in the State of Connecticut, the duration was one week. The program design, student and alums survey results, and identified high-impact activities were published in past proceedings of the American Society for Engineering Education Annual Conference & Exposition [8] and [9]. In 2019, this program was expanded from one week to two weeks for the first time, but it remained non-residential and only for high school students (rising 10-12 grades). A similar, two-week NSTI program was offered in 2023 after COVID disruptions. The same survey questionnaires were used to measure students' satisfaction, collect self-reported program impacts, and evaluate five educational instruments in the years 2019 and 2023. Due to small sample sizes in both years and similarities in program activities, program participants' evaluations did not have a significant variance that justifies statistical analyses using two different samples. Therefore, no statistical analyses were conducted to differentiate pre- and post-COVID program evaluation results, and data from these two years were combined, resulting in a sample size of thirty.

Program Overview

The NSTI at Central Connecticut State University program introduces a wide range of STEM and transportation topics through carefully designed curriculum activities, including lectures led by professors, hands-on laboratory exercises tailored to engage teenagers, presentations by transportation practitioners, and a few field trips. In addition, a welcome luncheon, a SAT preparation session, team-building exercises, and a graduation ceremony are vital components of the program. Additional modules are added to the curriculum when the program is expanded from one week to two weeks, such as a campus tour, an OSHA safety presentation, a job shadowing field trip, a visit to a precast concrete plant, geotechnical engineering, a field trip to a highway construction site, submarine vehicle design and competition, engineering surveying, sustainability, visit to a "green building", and aerospace impact analysis. To accommodate students who take public transit to the host university campus, one hour in the morning and one hour in the afternoon are allocated to social interactions and arrival/departure. During this time, students can play various games in the Student Center while waiting for the first activity to start or to be picked up by their parents; students can also choose to arrive late or leave early to take a bus. A sample program schedule is given in Table 1, with added modules highlighted in grey.

This NSTI program is well supported by the host university, government agencies, local professional associations, and private firms. Different entities play special and meaningful roles, presenting an integrated approach to increasing high school student's knowledge of and interests in STEM. More specifically, participating faculty at the host university offer their technical expertise in a spectrum of subject matters. The FHWA Division Office provides timely guidance on the implementation of the program. Connecticut Department of Transportation liaisons provide guidance on program design, recommend activities and speakers, and coordinate the graduation ceremony held at the agency’s headquarters.

Table 1. Sample Schedule
First Week

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8:00 -- 8:30	Welcome & Survey	Arrival (Game Room of the Student Center)			
8:30 -- 9:00					
9:00 -- 9:30		Safety (OSHA)	Aircraft Design & Competition	Geotechnical Engineering & Lab	SAT Prep
9:30 -- 10:00	Team Building & Exercise				
10:00 -- 10:30					
10:30 -- 11:00	DOT Guest Presentations	Transportation Safety			
11:00 -- 11:30					Student Survey & Feedback
11:30 -- Noon					
Noon -- 12:30	Welcome Luncheon	Lunch	Lunch	Lunch	Lunch
12:30 -- 1:00					
1:00 -- 1:30		Job Shadowing Field Trip	Precast Concrete Plant Field Trip	Construction Field Trip	Helicopter/Drone Design & Simulation
1:30 -- 2:00	College Admissions				
2:00 -- 2:30	Safety (Police)				
2:30 -- 3:00					
3:00 -- 3:30	Campus Tour				
3:30 -- 4:00					
4:00 -- 4:30	Departure (Game Room of the Student Center)				
4:30 -- 5:00					

Table 1. Sample Schedule (continued)
Second Week

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8:00 -- 8:30	Arrival (Game Room in the Student Center)				
8:30 -- 9:00					
9:00 -- 9:30	Submarine Vehicle Design & Competition	Sustainability	Engineering Materials & Lab	Aerospace Impact Analysis	DOT Headquarters Visit
9:30 -- 10:00					
10:00 -- 10:30					
10:30 -- 11:00					
11:00 -- 11:30					
11:30 -- Noon					
Noon -- 12:30	Lunch	Lunch	Lunch (on bus)	Lunch	Lunch (at DOT)
12:30 -- 1:00					
1:00 -- 1:30	Engineering Surveying & Lab	Green Building Field Trip	Air Museum	Bridge Design & Competition	Graduation Ceremony
1:30 -- 2:00					
2:00 -- 2:30					
2:30 -- 3:00					
3:00 -- 3:30					
3:30 -- 4:00					
4:00 -- 4:30	Departure (Game Room in the Student Center)				
4:30 -- 5:00					

Another valuable partner to this NSTI program is the Women's Transportation Seminar (WTS) local chapter, which is recognized as a Gold Status Chapter by the WTS International Circle of Excellence, the highest status WTS International awards. Each time this program is offered, a small group of passionate women talk about their career paths and exciting projects; some also participate in the welcome luncheon and graduation ceremony. In addition, WTS recently established two $500 scholarships for NSTI students who need financial support to attend this meaningful summer program. When recruiting high school students, the NSTI Director noticed that some students expressed interest in the program but said they had to work during summer to support themselves and their families. Apparently, the paid transportation costs, free meals, and exciting STEM-focused curriculum were not enough for these students in financial hardship. After approval from the Student Outreach and Scholarship Committee as well as the Executive Board, two NSTI scholarships were added to the WTS awards offered to high school, undergraduate, and graduate students in the State.

Last but not least, local private firms make important contributions in arranging field trips and supporting this NSTI program financially. For example, Vanasse Hangen Brustlin, Inc. or VHB, a multidisciplinary civil engineering consulting and design firm, recently committed $2,000 to cover program participants' meal costs for eight days (excluding the first and last days of the program when welcome luncheon and graduation ceremony will take place), which is unallowable as per the FHWA cost principles for non-residential programs. HNTB and AECOM hosted job shadowing events in their local offices, where students listened to industry speakers, interacted with professionals, and observed their daily activities.

This NSTI program focuses on promoting STEM educational and career opportunities to younger generations, with recruitment strategies targeting historically underrepresented groups. In 2019 and 2023, thirty-seven percent of the students (11 out of 30) were female. Nationwide, women comprised about 34% of STEM workers in 2019 [10]. The gender makeup of program participants generally represented the national trend. Seventy-seven percent of the students (23 out of 30) reported themselves as not being Caucasian, with 20% (6 out of 30) as African American and 33% (10 out of 30) as Hispanic. According to the 2019 American Community Survey, African Americans and Hispanic or Latino workers held about 9% and 14% of STEM jobs, respectively [10]. This program recruited more than double the minorities seen in the STEM workforce nationally, demonstrating the success of this program's recruitment strategies.

When asked how participants heard about this program, many (47% or 14 out of 30) said they learned of this opportunity from "school". This was consistent with student recruitment efforts. This program was advertised to all high schools in the State using a contact directory compiled by the host university's Admissions Office. Program flyers and application forms were emailed to high school counselors and principals/directors. Paper copies were sent to high school principals/directors via ground mail. Noticeably, many program participants (47% or 14

out of 30) heard about this program from “family or friends”, which increased by more than ten percent from a few years ago. This shows the importance of family/friend support when inviting youth to enter STEM educational opportunities and indicates past students could serve as advocates and help recruit future students for an established summer outreach program.

A remarkably high percentage of participants' parents graduated from college – 83.3% of the mothers and 50.0% of the fathers graduated from college, as compared to a national average of 39.0% for females and 36.2% for males aged 25 and over who have at least bachelor’s degrees [11]. It is clear that parents’ educational backgrounds are a noteworthy factor in high school students' participation in this STEM-focused summer outreach program. In addition, of the thirty participating students, mothers of 36.7%, fathers of 36.7%, and relatives of 33.3% work in STEM-related jobs. These numbers are higher than the 23% of the total U.S. workforce that are STEM workers [12]. Apparently, when high school students are exposed to STEM in their early years because a parent or relative works in a STEM-related field, they are generally more interested in STEM and more aware of opportunities in STEM.

An opening survey, a mid-program survey, and an end-of-program survey are conducted to assess this NSTI program’s impacts on students and seek input from participants to make continuous improvements to the program. Minor changes are made to the questionnaires related to specific program activities, but most questions remain the same. A few questions are repeated in the mid-program and end-of-program surveys to discover the incremental influences of this program over two weeks.

Program Assessment

Overall, this NSTI program is well received and deemed helpful by program participants. According to the mid-program and end-of-program surveys, more than 90% of the students were either “highly satisfied” or “satisfied” with their overall experience, showing a strong satisfaction of the participating students on a balanced and well-supported summer program described in the previous section. Only two students (out of thirty) changed their rating from “satisfied” to “partially satisfied” between these two surveys. The following section has a detailed discussion on the distribution of student satisfaction and how it changes over time.

In both surveys, more than 95% of the students reported that they either “strongly agree” or “agree” that this program improved their knowledge of STEM. In addition, more than 65% of the students either “strongly agree” or “agree” that this program made them *more likely* to pursue college education in STEM. Additional analyses on the response distribution and change over time are presented in the following section.

This program utilizes five distinctive educational instruments: industry speakers, presentations by professors, lab exercises, design & competition, and field trips. It is worth noting that the second and third instruments can happen in the same module, and the second and fourth can occur in the same module. To adapt to the learning style of high school students, professors usually have a short presentation/lecture, followed by a lab exercise or a student design and competition. But presentations/lectures are separated from the following hands-on activities because the nature of student involvement is quite different. Program participants are asked whether they agree that these five educational instruments help them better understand STEM principles and/or applications. The same set of questions is included in the mid-program and end-of-program surveys, and the following discussion is based on the average of these two survey results, meaning no distinctions are made between two activities in separate weeks if they are the same type of educational instruments. Student responses are illustrated in Figure 1.

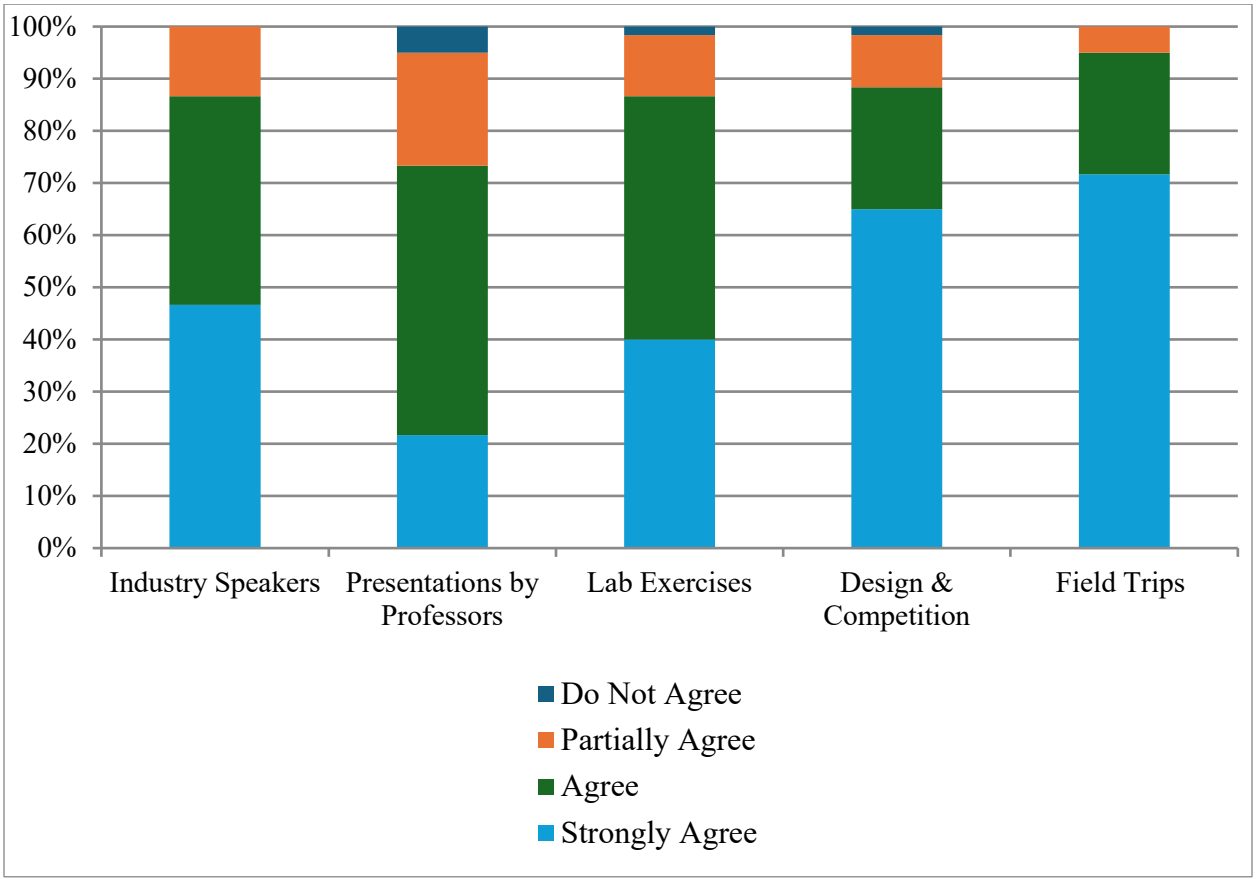

Figure 1: Response Distributions on Whether Participants Agree the Educational Instruments Help Them Better Understand STEM Principles and Applications

A four-point scale is used to analyze student evaluations – 1 being "not agree", 2 being "partially agree", 3 being "agree", and 4 being "strongly agree". The educational instrument that is the most popular and effective in helping high school students better understand STEM

principles and applications is field trips, with a weighted average of 3.67, followed by design & competition, whose score is 3.52. Industry speakers and lab exercises receive a weighted average of 3.33 and 3.25, and presentations by professors is the least favorite and effective with a score of only 2.90. An introduction of the basic concepts to be used in a lab exercise or a student competition is essential, but it may be a good idea to keep such presentations to a minimum.

Open-ended questions showed that high school students enjoyed hands-on exercises, competitions, and field trips, which was supported by student evaluations of educational instruments using a four-point scale. For example, one student wrote, "I really enjoy when there is a hands-on activity that follows the presentation … I also like going on the field trips to see real world applications." Another student said, "I really enjoyed the field trips and the competitions we had. Those were very interesting. On the other hand, I didn't enjoy lectures as much". Some positive comments include "I've learned a lot of things throughout these 2 weeks and it's a huge opportunity for me because I've never been exposed to STEM like this", "it was fun and helped me with knowledge about STEM and other principles I will use in life", and "I enjoyed mostly everything".

While many students suggested fewer lectures, one student commented that "it was very exciting being introduced into some of the aspects of STEM and being able to conduct experiments … The activities were made by college professors but very understandable by rising 10th to 12th graders." This comment reflected instructors' efforts in designing and delivering lectures appropriate for high school students; maybe the number of lecture slides and the length of presentations could be reduced based on student feedback.

When asked about any recommended changes for future NSTI programs, a few students left the question blank, indicating they were happy with the program and had no suggestions. Some students just gave positive comments rather than suggestions. For example, one student wrote, "I will not change a bit about the programs. I think I know this is a good program when my sister goes to freshman year I'm going to tell her", and another student responded, "no, not really it was very fun and organized". There were also many constructive recommendations that are presented and discussed in the Lessons Learned section of this paper.

Incremental Analysis of Student Evaluations

The mid-program and end-of-program surveys share a few identical questions, providing an opportunity to identify areas for improvement in a timely manner. Such survey designs also generate additional data for analyzing how this program impacts students during the two-week program duration and how participants' self-reported evaluations change over time.

When rating their overall experiences, 36.7% of the students (11 out of 30) chose “highly satisfied”, 63.3% (19 out of 30) were “satisfied”, and none selected the “partially satisfied” or “not satisfied” options after one week of the program; responses changed to 43.3% “highly satisfied”, 50.0% “satisfied”, 6.7% “partially satisfied”, and 0% “not satisfied” at the end of this two-week program. Figure 2 shows student satisfaction with the program and its changes in two weeks. Using a scale of 1 being “not satisfied”, 2 being “partially satisfied”, 3 being “satisfied”, and 4 being “highly satisfied”, the weighted average for both the mid-program and end-of-program surveys is 3.37, showing no changes in student evaluations of their experiences during the program.

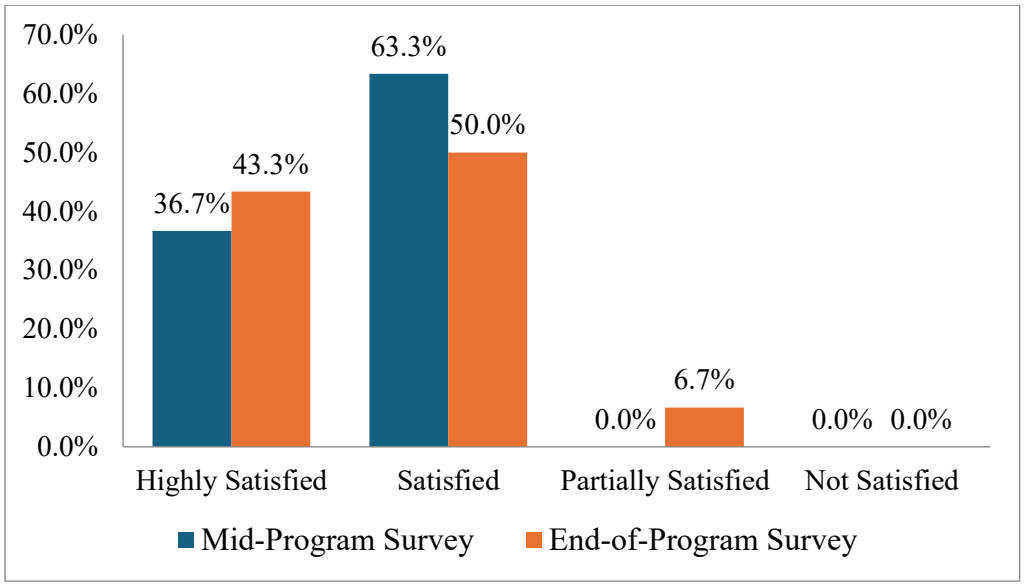

Figure 2: Response Distributions on Overall Experience in the Program

It is encouraging to see a percentage increase in the “highly satisfied” category as the program goes on, but at the same time, there is an increase in the “partially satisfied” category. A close examination of the original data revealed that two students downgraded their overall experience from “satisfied” to “partially satisfied”. It was also found that one of these two students didn’t have any comments/suggestions in either survey, and the other student commented, "It was fun but some activities weren't fun” in the end-of-program survey. One possible reason could be that some of the curriculum activities in the second week didn't match this student's interests.

When asked whether they agreed this program improved their knowledge of STEM, 40% of the students (12 out of 30) responded they “strongly agree”, 56.7% (17 out of 30) said they “agree”, one student (3.3%) chose “partially agree”, and none selected “not agree” in the mid-program survey; responses changed to 56.7%, 40.0%, 3.3%, and 0% for the four options at the end of this program. Figure 3 shows students’ self-evaluation of their STEM knowledge improvement and how such evaluations change over time. Using a scale of 1 being “not agree”,

2 being “partially agree”, 3 being “agree”, and 4 being “strongly agree”, the weighted average for the mid-program and end-of-program surveys increases from 3.37 to 3.53, indicating a positive impact of program duration on students’ self-reported confidence in their STEM knowledge.

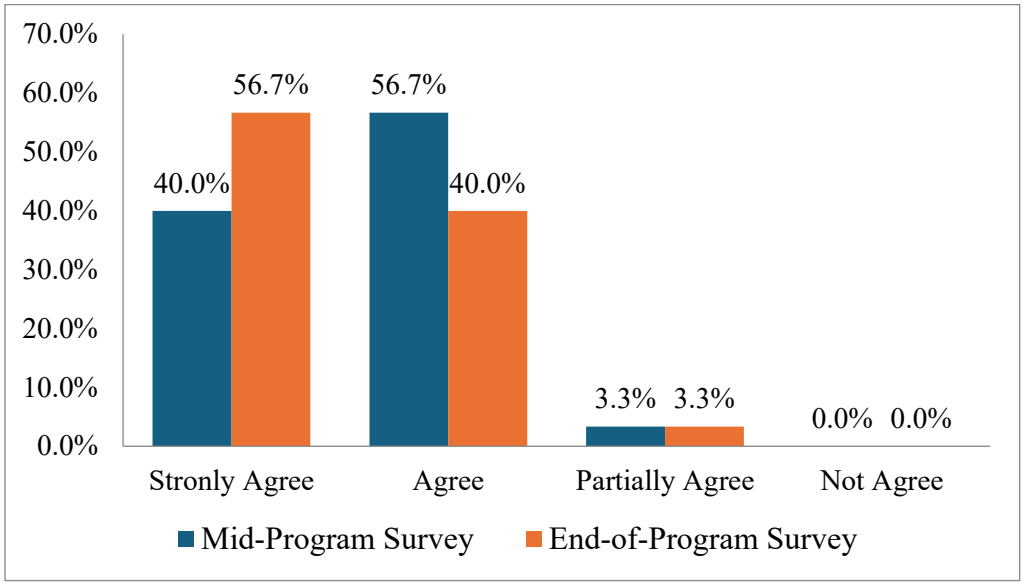

Figure 3: Response Distributions on Whether Participants Agree This Program Improved Their Knowledge of STEM

One NSTI program goal set by FHWA is to encourage participants to pursue transportation-related courses of study at the college/ university level [7]. Responses to one question designed to assess this outcome in the mid-program and end-of-program surveys are shown in Figure 4. When asked whether they agreed this program made them *more likely* to pursue college education in STEM, 30% of the students (9 out of 30) chose “strongly agree”, 36.7% (11 out of 30) said they “agree”, 30.0% (9 out of 30) were “partially agree”, and one student (3.3%) did “not agree” in the mid-program survey; responses changed to 16.7%, 50.0%, 33.3%, and 0% for the four options at the end of this program. Using a four-point scale – 1 being “not agree” and 4 being “strongly agree”, the weighted average for the mid-program and end-of-program surveys decreases from 2.93 to 2.83, indicating this program didn’t increase students’ probabilities of studying STEM in college as students participate in more STEM-focused activities.

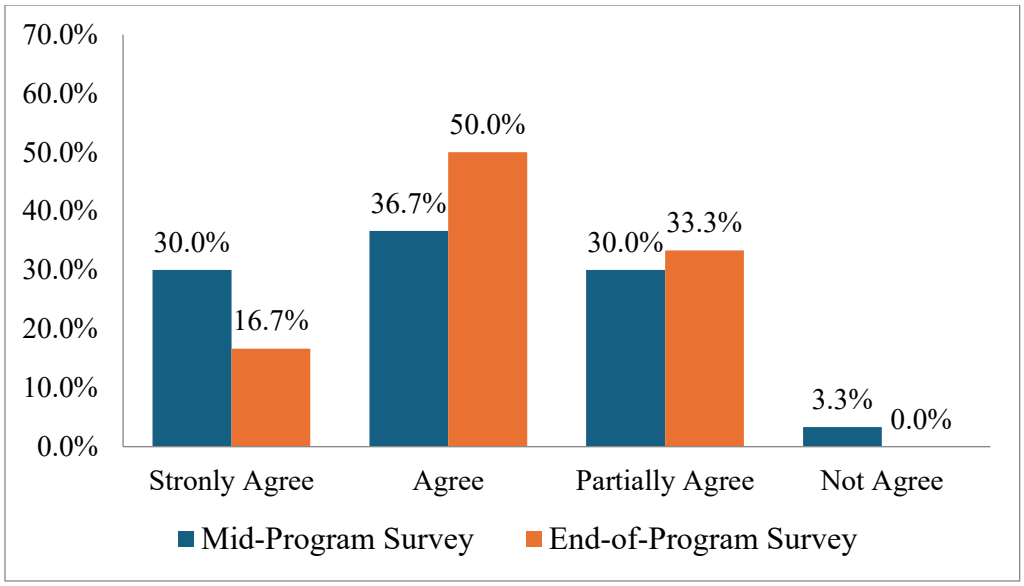

Figure 4: Response Distributions on Whether Participants Agree This Program Made Them *More Likely* to Pursue College Education in STEM

This important program evaluation criterion merits further examination. First, the sample was divided into two groups: female vs. male. Using the same four-point scale mentioned previously, female students' responses on whether the program made them *more likely* to pursue college education in STEM decreased from 3.09 to 2.73, while male students' responses increased from 2.84 to 2.89. Even though the increase for males is marginal, the analysis demonstrates the differential impacts of this STEM-focused program on students' likelihood of studying STEM in college by gender.

Second, students whose parents/guardians or relatives do not work in the field of STEM were separated from the rest (who have at least one parent/guardian or relative working in a STEM field). The weighted average using the four-point scale dropped from 3.08 to 2.68 for students whose parents and relative(s) are not STEM workers; these students are generally not exposed to STEM career perspectives at home or family events. In contrast, the weighted average increased from 2.82 to 2.94 for students who have at least one parent/guardian or relative working in a STEM field; these students may receive influences from family members on pursuing STEM jobs. Like the discovery related to gender, the program duration has differential impacts on students with different family backgrounds.

Lessons Learned

In mid- and end-of-program surveys, students offer written comments on improving future NSTI programs. A couple of students suggested that the first day ends with some fun activities. As shown in Table 1, the first day has a few short information sessions and a welcome luncheon, leaving limited space for a fun hands-on experience. In the future, college admissions,

safety training/presentation by the university police, and a campus tour can be moved to the second day of the program. Such adjustments will free the first day afternoon for a student design and competition that is considered fun by many students.

A few comments relate to the time needed to complete a project in student competitions. While no teams withdrew from competitions in the past because they couldn't finish their projects, such student comments were passed along to the individual instructors for their consideration.

A couple of students commented on the program starting time and length in a day – "it is just a little too early for us, kids will still be sleepy and might sleep during lectures making the lectures ineffective. A good time would be instead of 8 am, it should be 10 am" and "make the program last more days but less hours, 8 hours a day for some might make them hesitate from taking the opportunity". These students probably didn't know that the funding agency had determined the duration of this program well ahead of time. Given that, fewer hours a day or starting each day later will mean fewer activities in this program. Questions on program starting time and length in a day will be added to future survey questionnaires to further explore the best option for most participating students.

Other comments include more exercises to learn all student names, a field trip or a design & competition about train travel, keeping the scavenger hunt in the museum field trip, and more options for lunch. Additional team-building exercises, keeping the scavenger hunt, and finding a better lunch menu are easy to implement, but recruiting a qualified instructor on train travel or arranging a field trip on this model of transportation can be challenging.

Last but not least, one student commented, "I really liked that you gave us breaks, I think it was very effective in the ways that we were learning." This is a positive comment on a best practice, but it is added here for other outreach program directors to consider in their program design and administration.

Conclusions

A National Summer Transportation Institute (NSTI) program at Central Connecticut State University program is designed to improve Science, Technology, Engineering, and Math (STEM) skills by providing high school students, minorities, young women, and disadvantaged youth with awareness regarding careers in transportation and to encourage them to take transportation-related technical curricula in pursuit of a transportation career. It offers lectures led by college professors, laboratory exercises, presentations by professionals, field trips, and other enrichment activities. The program is recently expanded from one week to two weeks, offering a unique opportunity to discover the incremental impacts of such interventions on high school students'

improved STEM knowledge and skills as well as plans to pursue college education in STEM. There is no doubt that this summer outreach program has measurable benefits in increasing high school students' confidence and interest in STEM, but differential impacts exist by gender and family backgrounds.

In addition, this paper presents the program design and schedule, demographic characteristics of participants, as well as student evaluations and lessons learned based on the mid-program and end-of-program surveys in the years 2019 and 2023. Five educational instruments, including industry speakers, presentations by professors, lab exercises, design & competition, and field trips, are evaluated using ordered ranks. Field trips and design & competition are the most popular among program participants and the most effective in helping high school students better understand STEM disciplines and applications. While professors paid attention to designing and delivering lectures appropriate for high school students, the lecture length probably needs to be reduced to the key principles/concepts to keep program participants interested and engaged.

This NSTI program takes an integrated approach in which the host university, government agencies, local professional associations, and private firms play special and meaningful roles. This integrated approach offers additional financial support to all students as well as those in need. It also makes students more convinced that a STEM college education is feasible and rewarding by providing them with diverse perspectives and showing them there are many people genuinely interested in helping them achieve their future success.

The incremental analysis of student evaluations shows no changes in students' satisfaction throughout the program and a positive impact of program duration on students' self-reported confidence in their STEM knowledge. Regarding program participants' likelihood of pursuing a college education in STEM, more STEM-focused activities or longer program duration didn't increase the self-reported probabilities. However, this study discovers differential impacts of the program duration on students with different gender and family backgrounds, revealing challenges of engaging females or students who are generally not exposed to STEM career perspectives at home or through relatives.

This study utilizes state-preference surveys suitable for program evaluation but with inherent limitations. No objective measures of STEM learning were sought in 2019 and 2023, but these can be designed and implemented in future NSTI programs. Another way of correcting potential bias in state-preference surveys is to conduct a reveal-preference survey, which shows the actual field of study in college (i.e., STEM vs. non-STEM). Additional efforts and research activities are needed to advance knowledge in this pre-college engineering education area.

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