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Identifying High Impact Activities in Stimulating STEM Interests among High School Students (Evaluation)

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Introduction

Many pre-college outreach programs were developed and implemented nationwide to increase high school students' interests in science, technology, engineering, and mathematics (STEM). Plentiful prior studies [1], [2], [3], [4], [5], and [6] documented positive impacts of such efforts using exit interviews. This paper evaluates a STEM-oriented summer program designed for high school students and examines the effectiveness of its educational instruments, using an opening survey, an end-of-program survey, and an alumni survey. Activities of high impacts identified by this study can be used by other similar outreach programs that aim to increase high school students' interests in STEM.

The National Summer Transportation Institute (NSTI) program is one of the Federal Highway Administration's (FHWA) educational initiatives. It is "to increase awareness and stimulate interest in transportation to middle and high school students" and "exposes students to the transportation and encourages them to pursue transportation-related courses of study at the college and university level" [7]. The NSTI program presented in this paper is hosted by Central Connecticut State University (CCSU). It recruits high school students with diverse demographic and academic background, and focuses on raising participants' awareness in STEM educational and career opportunities. Program evaluation results demonstrate how high school students' interests in STEM can translate into engineering pipeline growth. Program participants' perceptions and preferences shed lights on effective course delivery in engineering education.

Program Overview

The NSTI at CCSU program is a one-week, non-residential program for rising 9-12 graders in summer. Land, water and air transportation modes are introduced through carefully designed curriculum activities, such as lectures led by college professors, hands-on laboratory exercises, presentations by transportation professionals, and field trips. Program undergoes improvements each year, but the basic curriculum remains the same.

The NSTI at CCSU program utilizes strategies to recruit high school students with diverse demographic backgrounds. Application package and program flyer are distributed to high school counselors in the state. Interested students can submit paper applications via ground mail or fax, or apply online at the program's website. This program also seeks assistance from other educational institutes that share similar missions. Applicants need to have a minimum cumulative grade point average of 2.0 on a 4.0 scale, and are selected primarily based on the letter of recommendation and a personal statement.

Among the forty-one program participants from two consecutive years, 32% (13 out of 41) are female, and 66% (27 out of 41) reported themselves as not being Caucasian, with 37%

(15 out of 41) as African American and 7.3% (3 out of 41) as Hispanic. 24.4% of participants (10 out of 41) reported their annual household income as less than $30,000. In addition, high percent of participants' parents graduated from college: 61.0% of students' mothers graduated from college and 58.5% of students' fathers graduated from college. Additional program details can be found in [8].

End-of-Program Assessment

The NSTI at CCSU program incorporates two surveys to assess program success and to improve curriculum design: an opening survey and an end-of-program survey. Most questions in the two surveys remain the same over time, ensuring consistence in program assessments. The opening survey is conducted in the Monday morning before the program starts, and the end-of-program survey is right before a graduation ceremony in the State Department of Transportation headquarters. Program director from the host university distributes and collects the survey questionnaires, ensuring each student has enough time to complete all questions. Six students were removed from the following analysis because they did not fully complete both surveys, reducing the sample size from forty-one to thirty-five. The sample size is relatively small, but is believed to be sufficient for most statistical analysis conducted in this study.

In general, program participants are satisfied with this program. One question in the end-of-program survey asks students to rate their overall experience: 51% (18 out of 35) respond that they are "highly satisfied", 46% (16 out of 35) are "satisfied", none are "partially satisfied", and 3.0 % (1 out of 35) choose "not satisfied".

Both the opening and end-of-program surveys collect data on participants' self-reported probabilities of pursuing college education in STEM. These two surveys are five days apart, with only the NSTI at CCSU program in between. Any changes recorded can be primarily contributed to the interventions brought by this program. The available five options in probabilities of pursuing college education in STEM are: "very likely (> 80% chance)", "probably (80% - 60% chance)", "decent chance (59% - 40% chance)", " maybe (39% - 20% chance)", and "probably not (< 20% chance)". Before the start of this program, 57 % (20 out of 35) choose "very likely", 26% (9 out of 35) choose "probably", and only one student chooses "maybe". After one week of submerging in this STEM-oriented program, participants, as a whole, have a slightly increased probability: 71 % (25 out of 35) for "very likely", 14% (5 out of 35) for "probably", and two students choose "maybe". No one reported the lowest probability in either survey. Figure 1 summarizes the response distributions.

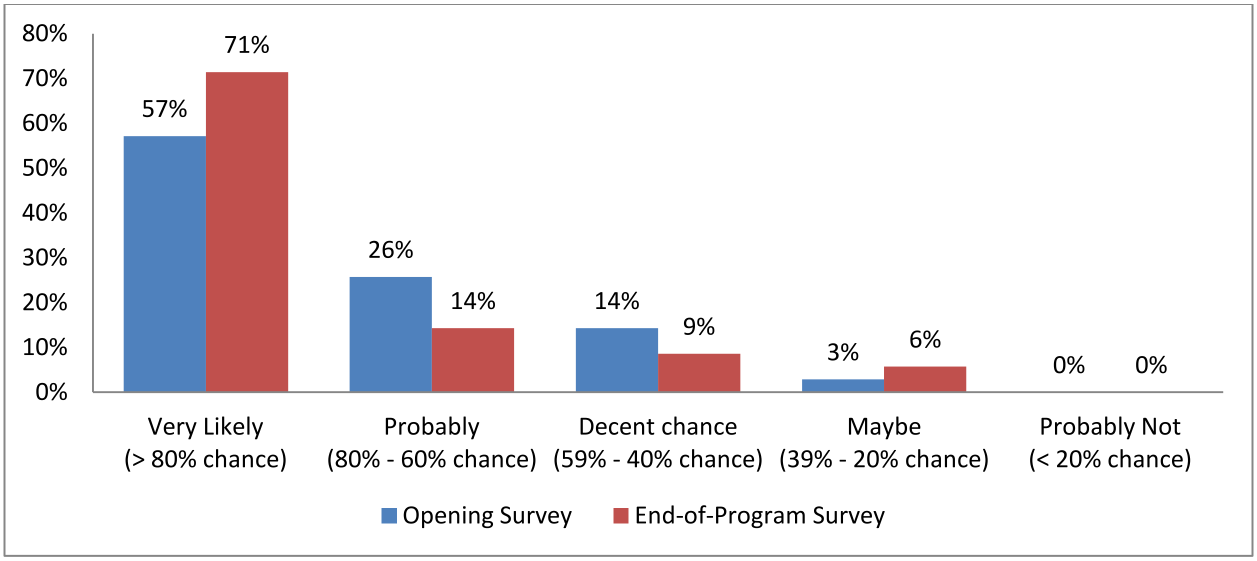

Figure 1: Response Distributions on Participants' Probabilities of Pursuing College Education in STEM in the Opening and End-of-program Surveys

This shift is more apparent when using numerical representations: 5 being the highest probability and 1 being the lowest probability. The weighted average of all responses changes from 4.37 to 4.51, due to attending the NSTI at CCSU program. While program participants clearly have high potentials in STEM fields, this outreach program strengthens their interests to some extent.

A closer examination on the survey questionnaires reveals that five participants reported decreased likelihood of pursuing college education in STEM from the opening survey to the end-of-program survey. Among them, three are female, one is African-American male, and one is Caucasian male. Given this program's participant demographic makeup, minorities (e.g., female and non-Caucasian) seem benefit less, as compared to their counter-parts.

The end-of-program survey also evaluates five educational instruments used in the curriculum: software demonstration, simulator operation, material testing, building exercise and competition, and field trips. Software demonstration appears in a few different modules. For example, students explore the ModelSmart3D software after learning fundamental statics concepts and bridge design principles, and use the X-plane software to learn basic concepts of helicopter design and operation. Simulator operation is a unique component in the NSTI at CCSU program. A prototype helicopter simulator was developed and built by a faculty member and his students at the host university through a National Aeronautics and Space Administration (NASA) research grant. Program participants, who are interested in operating a helicopter, are supervised to "fly a helicopter" in a laboratory environment. Material testing instrument includes a series of demonstrations on steel and concrete mechanical property testing: a concrete compassion test, a steel impact test of, a steel fatigue test, and a steel tension test. Students are split into small groups and can operate testing apparatus to their comfort levels. Building exercise and competition is applied multiple times in the curriculum: a balsa wood bridge design competition, a lock and dam system competition, and a form-board airplane design competition. These three activities are described in detail in the "High Impact Activities" section. Field trip is essential to the NSTI at CCSU program. In each of the two consecutive years, students visited at least two among the following four places: the State Department of Transportation headquarters, a state landmark project, a regional airport, and a sea port.

In the end-of-program survey, participants are asked to rate whether each educational instrument helps them better understand STEM principles and applications. The available four options are: "do not agree", "partially agree", "agree", and "strongly agree". Participant responses are illustrated in Figure 2. It is obvious that building exercise and competition is the most popular and effective in helping high school students better understand STEM principles and applications.

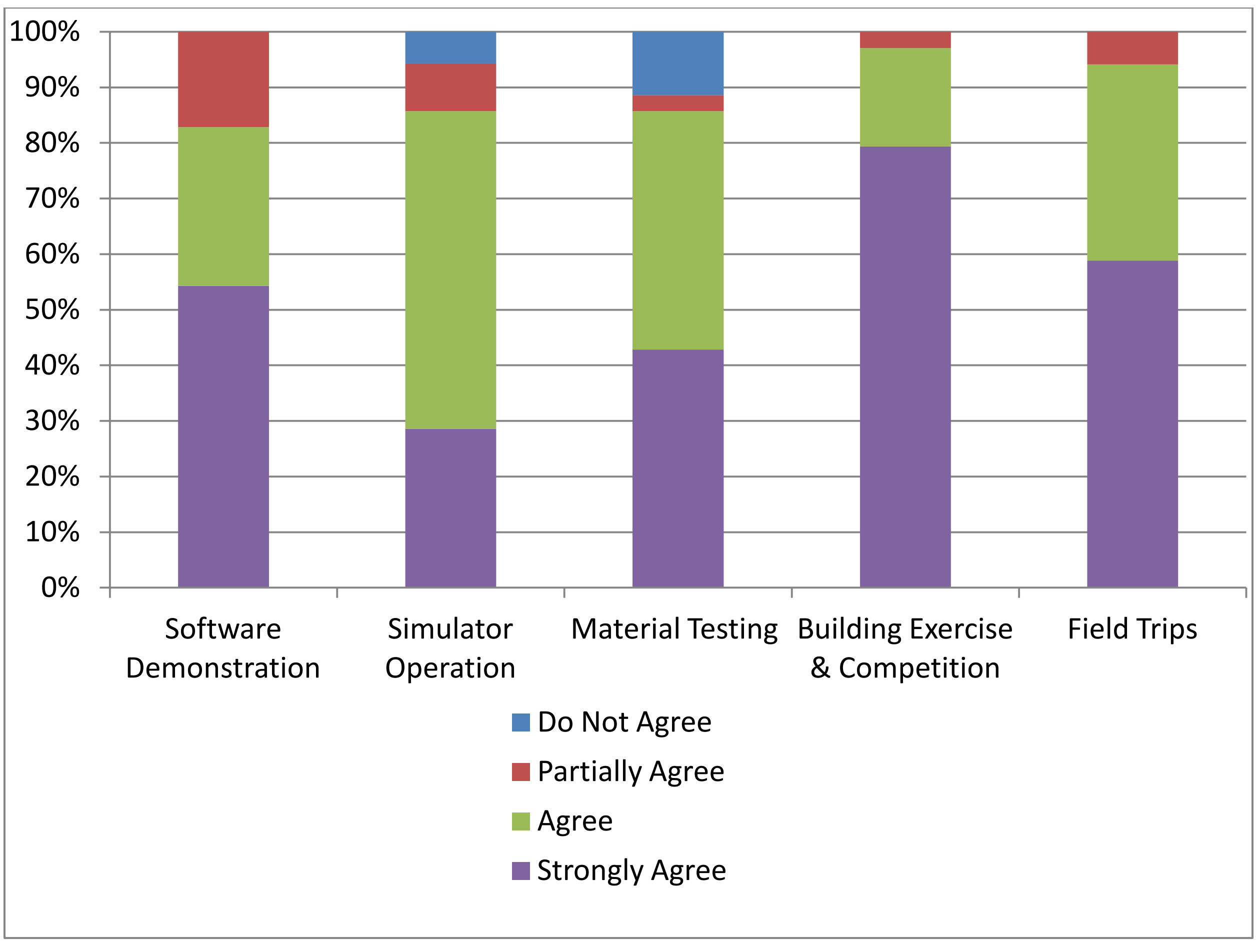

Figure 2: Response Distributions on Whether Participants Agree the Educational Instruments Help Them Better Understand STEM Principles and Applications

In addition to the above graphic demonstration, numerical results can also reveal the effectiveness of these educational instruments. Using a scale of four: 1 being "do not agree", 2 being "partially agree", 3 being "agree", and 4 being "strongly agree", the building exercise and competition instrument receives the highest score of 3.76, field trips has the second highest score of 3.53, software demonstration has a score of 3.37, and two educational instruments with the lowest scores are simulator operation (3.09) and material testing (3.17). These assessment results show that high school students learn more effectively through hands-on activities after understanding relevant principles or theories, and passive learning (in observing material testing, for example) is not what high school students would prefer when gaining STEM knowledge.

Long-Term Program Assessment

In addition to positive impacts in promoting STEM, some pre-college outreach programs reported encouraging effects in terms of alumni's college pursuits [9], [10], and [11]. The NSTI at CCSU program alumni were also invited to complete a follow-up survey one year or two years after they finished the program. This survey is designed to determine the long-term effects of this program on participants' STEM inclination and their actual college education choices. Among the thirty-five program alumni who completed both the opening and end-of-program surveys, twenty-three participated in the alumni survey administrated online, resulting in a response rate of 66%. Following discussions focus on the three aspects described in the previous section: overall experience with the program, stated probability of pursuing college education in STEM, and evaluation of five educational instruments.

When asked to rate their overall experience one year or two years after graduating from the NSTI at CCSU program, 61% of the respondents (14 out of 23) choose "highly satisfied", 35% (8 out of 23) respond they are "satisfied", 4.0 % (1 out of 23) choose "partially satisfied", and none are "not satisfied". Figure 3 depicts the response distribution from this alumni survey, with the end-of-program survey results shown as a comparison.

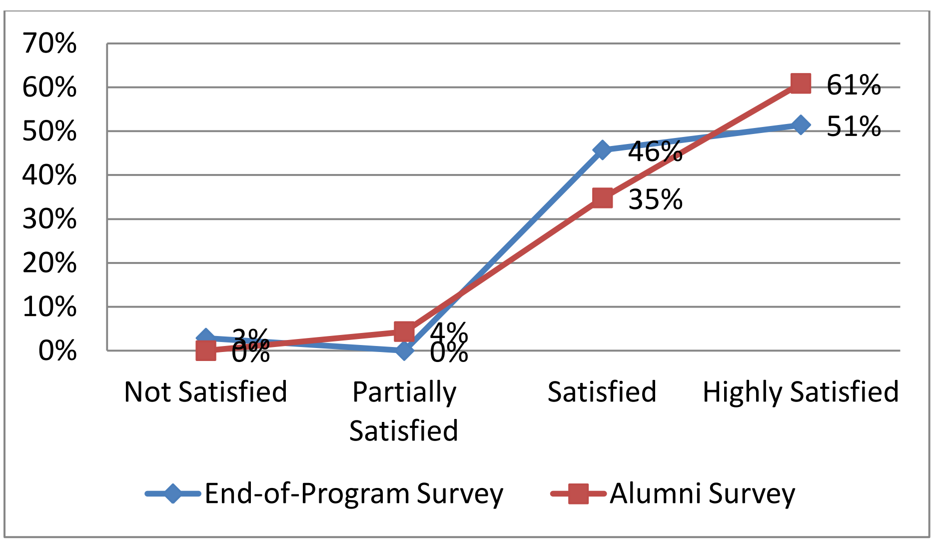

Figure 3: Response Distributions on Overall Program Experience in the End-of-Program and Alumni Surveys

If these ordered responses are represented by numerical values (4 being highly satisfied and 1 being not satisfied), the weighted average is 3.57 in the alumni survey, increased slightly from 3.46 in the end-of-program survey. It may be argued that self-selection bias could play a role in the slightly increased rating score. In other words, less satisfied alumni do not participate in this follow-up survey years after the program is over, making the rating score higher than before. If self-selection bias exists in this study, the overall experience rating score in the alumni survey could be artificially inflated. However, a paired comparison between the end-of-program survey and the alumni survey shows that the majority respondents have the same rating as time passed by. 74% of the respondents (17 out of 23) give the same score in these two surveys, even though they normally do not have a clear memory of the options they chose one year or two years ago. Five alumni increase their scores by one level, and one program graduate decrease his/her score by one level. It can be concluded that long-term program evaluations do not deviate much from the short-term results.

Like the opening and end-of-program surveys, this alumni survey asks program participants, who are still in high school, their probabilities of pursuing college education in STEM. The same five ordered options (e.g., "very likely", "probably", "decent chance", "maybe", and "probably not") are provided. Among the thirteen alumni who are still in high school, only one reports an increased probability (from "decent chance" to "very likely") and all the other twelve state exactly the same level of likelihood as they did in the end-of-program survey.

In addition, among the ten alumni who graduated from high school already, all attend college and nine (or 90%) choose a STEM major. This percentage of actual enrollment in STEM fields is comparable to the likelihood discovered by the end-of-program survey. It, again, shows the enduring impacts of this NSTI at CCSU program.

These findings are remarkable because of the following three reasons. First, program alumni do not have access to their past survey answers, but their responses are very stable. In other words, the long-term survey (i.e., alumni survey) matches well with the short-term survey (i.e., end-of-program survey) in terms of overall satisfaction and self-reported probability of pursuing college education in STEM. Second, if an end-of-program survey can deliver accurate estimates on students' program evaluations and stated interests in STEM, a long-term assessment is not necessary, especially when resources are limited. Last, as discussed in the previous section, this outreach program strengthens participants' interests in STEM to some extent (shown by the slightly increased probability of pursuing college education in STEM due to program participation), and this increase is now found to remain almost unchanged over time. The implication is this outreach program is meaningful in promoting STEM disciplines among high school students, and more importantly, such positive impacts do not easily decay over time.

A closer examination on the opening and alumni surveys reveals that program alumni majoring in STEM have a strong inclination in STEM before attending the summer program, but this program enhances their interests and might have changed some participants' final decisions on major in college. It is worth mentioning that due to the relatively competitive selection process, many participants are inclined to attending college and majoring in STEM, as stated in their personal statements and teacher recommendation letters. Therefore, the outreach program itself can only have limited impacts on participants' college decisions and career paths. Among the nine who choose a STEM major in college, seven indicated that they were "very likely" (more than 80% chance) to pursue college education in STEM in the opening survey, and one chose "probably" (80% - 60% chance), and one chose "maybe" (39% - 20% chance). NSTI at CCSU program's impacts on the last two participants are noteworthy. The single graduate enrolled in a non-STEM major is currently studying management information system (MIS), and has indicated the highest probability of pursing a STEM major when responding to the opening survey. Nevertheless, MIS is relatively close to the technology aspect in STEM. Focusing only on these program alumni, the NSTI at CCSU program achieves its goal of promoting STEM among high school students.

The alumni survey asks past program participants to recall activities that help them better understand STEM, without providing them with any options to choose from or a list of the curriculum elements. A broad range of activities/events are mentioned by survey respondents in responding to this open-ended question. These activities /events are later grouped into categories, including the five educational instruments used in the end-of-program survey. Simulator operation and material testing, the two least effective educational instruments, are recalled by program alumni 4 and 2 times, respectively. Surprisingly, none of the alumni mention activities involving software demonstration. This is probably due to the wide availability of computers and software applications in our daily lives, making computer aided instructions an ordinary or even a must to high school students nowadays.

Field trips and building exercise/competition are the top two frequently listed educational instruments; they are mentioned 17 and 16 times, respectively. As described in the previous section, these two instruments are the most effective in helping program participants better understand STEM principles and applications. Apparently, high school students learn more effectively through hands-on activities, and more importantly, such learning experience can have a long-term impact on students' STEM readiness and inclination. These activities are deemed to be of high impact, and are presented in the following section.

High Impact Activities

As revealed by the short-term and long-term program assessments, building exercise and competition is the most effective educational instrument in helping high school students better understand STEM and such impacts do not easily change over time. It is recommended that educators and summer program directors incorporate such activities in their outreach programs, so young people can be challenged by and attracted to STEM principles and applications. Three curriculum modules that use this educational instrument are presented in detail here, including the bridge design and competition, the lock and dam design and competition, and the aircraft design and competition.

The bridge design and competition module is a miniature version of the renowned National Bridge and Structure Competition initiated by the American Association of State Highway and Transportation Officials (AASHTO) [12]. Students first learn some basic concepts in statics, and then are introduced to truss designs. Instructor leads discussions on pros and cons of a few truss configuration designs. Each student team (normally 4 to 5 students) chooses one design to build a truss bridge using balsa wood and wood glue guns, as shown in Figure 4. The competition is to award a team whose bridge has the highest strength-to-weight ratio. Each bridge is loaded gradually until collapse to determine its strength and is weighed right before loading. The bridge building exercise is timed; therefore, collaboration among team members is critical in producing a test-ready bridge on time.

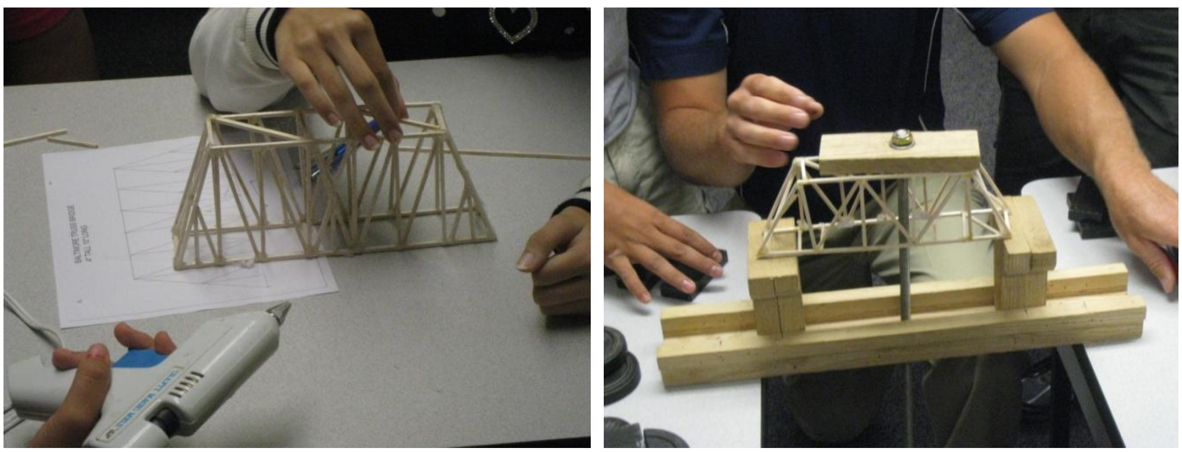

Figure 4: Bridge Design and Competition Photos

The lock and dam module challenges high school students with designing and building a model of a lock and a dam, using a large plastic tub, PVC trim boards, and modeling clay, as shown in Figure 5. Unlike in the previous exercise, student teams need to come up with their own designs, with assistance from the instructor. Hand saw, power drill, and drill press are used to shape PVC trim boards, and large board sections recycled from previous year(s) can be reused to expedite the building process. The instructor and at least one undergraduate student helper who is proficient with power tools need to be present during the entire laboratory exercise in order to ensure tool use safety. The model with the highest water elevation difference wins the competition. This module requires creativity in system design, proper material and tool handling, and collaboration among team members. It is more demanding than the bridge competition module. In two years of the NSTI at CCSU program, one team failed to finish building their lock and dam model, and therefore was disqualified for the competition.

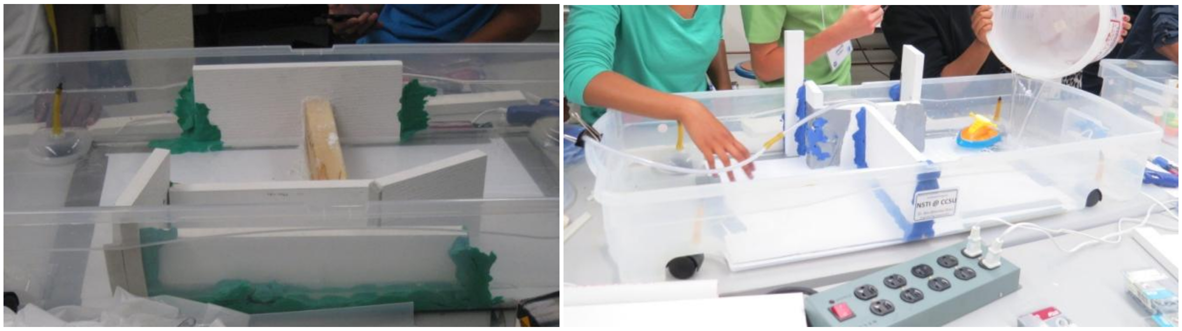

Figure 5: Lock and Dam Design and Competition Photos

In the aircraft design and competition module, students first learn some basic principles in fixed wing aircraft design, and then make their own aircraft models using foam boards and glue guns, as shown in Figure 6. Aircraft designs on paper need to be approved by the instructor before students can proceed to the building and competition stages. Students are encouraged to work individually, but small teams (2 members, for example) are allowed. Small objects can be attached to different locations on an aircraft to change the center of gravity and to facilitate flying of the aircraft. Students can explore such effects during their test fly and under supervision of the instructor. At the end of this session, aircraft that flies the longest distance is chosen as the winning design, regardless of weight or size. This module is the least challenging because the design process involves fewer steps and foam boards are easy to handle for high school students.

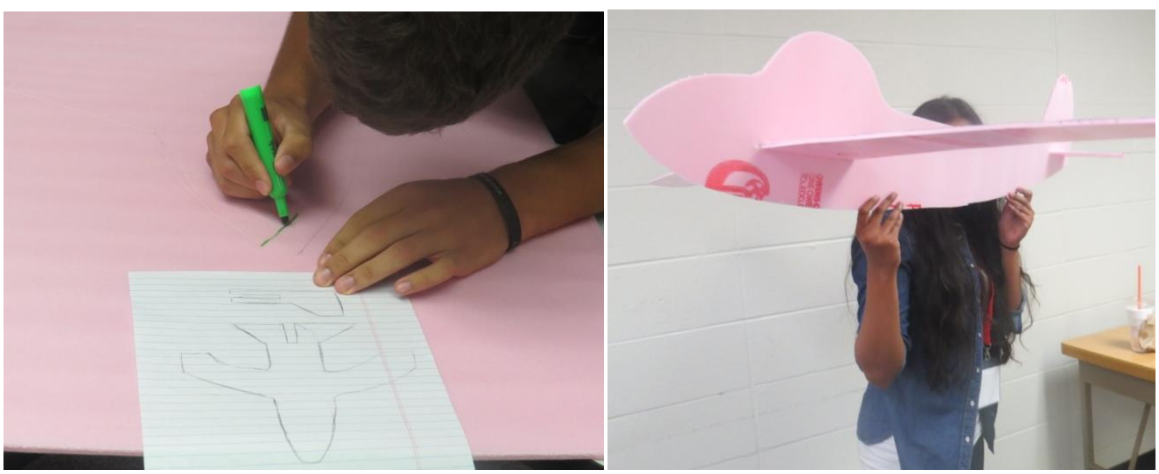

Figure 6: Aircraft Design and Competition Photos

Conclusions

A National Summer Transportation Institute (NSTI) at Central Connecticut State University (CCSU) program is designed to raise high school students' awareness in STEM educational and career opportunities. It offers lectures led by college professors, hands-on laboratory exercises, presentations by professionals, field trips, and other enrichment activities.

In each of the two consecutive years, a group of high school students with diverse demographic and academic background graduated from the program. This paper assesses this STEM-oriented outreach program using three surveys: an opening survey, an end-of-program survey, and an alumni survey. The opening survey collects data on program participants' probabilities of pursuing college education in STEM. This provides a baseline on students' interests in STEM. In the end-of-program survey, participants are asked to evaluate their overall experience and to report their probabilities of pursuing college education in STEM. These two questions are included in the alumni survey that is conducted one year or two years after program completion. Responses from these surveys demonstrate short-term and long-term evaluations of this outreach program and its effectiveness in promoting STEM among high school students.

Both the short-term and long-term assessments are very positive, and more importantly, this study discovers that such positive impacts do not easily decay over time. More specifically, the alumni survey (long-term) matches with the end-of-program survey (short-term) in terms of overall program satisfactions and participants' self-reported interests in pursuing college education in STEM. This finding supports investments in such outreach efforts because (1) there is a slight increase in participants' STEM inclination due to program intervention, and (2) this increase does not decay over time and therefore it can be materialized into improvements in STEM pipeline. Such finding also releases program directors from potentially time-consuming and costly long-term program evaluations, because assessment conducted using exit interviews/surveys is reliable and stable.

Five educational instruments are directly evaluated using ordered ranks in the end-of-program survey, and indirectly evaluated by asking past participants to recall program activities in the alumni survey. Building exercise and competition is the most effective in helping high school students better understand STEM disciplines and applications, and such activities have sustainable impacts on program participants one year or two years after they completed the program. High school students embrace the idea of a competition when learning STEM concepts and/or applications. The feeling of success associated with winning a competition or providing a design that demonstrates a successful attribute certainly is rewarding for young people who have high potentials in STEM fields.

To help other similar outreach programs design curriculum activities that attract young talent to STEM, this paper describes three modules of high impact: the bridge design and competition, the lock and dam design and competition, and the aircraft design and competition. They require minimal monetary investment, but do need knowledgeable subject experts (e.g., university faculty or experienced high school instructors) to offer guidance and technical support in the design phase, to administrate the competition, and to judge student designs before prizes are awarded. Hopefully, such information can assist educators and summer program directors in developing curriculum activities that match with high school students' learning styles, and thus stimulate greater interests in STEM among younger generations.

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