Implementation and Evaluation of an Engineering-Focused Outreach Program to Improve STEM Literacy (Evaluation)

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Abstract

This paper presents implementation and evaluation of an engineering-focused outreach program geared towards exposing the middle and high school student population, especially underrepresented and underserved groups, to science, technology, engineering, and mathematics (STEM) fields and careers. The STEM Academy project is a partnership between NASA, Elizabeth City State University (ECSU), school districts, state agencies, and other STEM enrichment programs. The program adopted a well-established NASA STEM curriculum with problem-based learning at its core and integrated 3D design and printing technology, sensor-based measurement systems, and engineering design activities such as roller coaster design and mini Unmanned Aerial Vehicle (UAV) design to enhance authentic and experiential learning experiences. Curriculum was delivered through the combination of summer and academic year hands-on activities complemented by guest speakers and field trips. The program targeted rural counties of the state and served 523 students (middle and high school) who received 36-40hours of hands-on STEM experience. Evaluation data and results were gathered through STEM Career Interest Surveys (STEM-CIS), student interviews, teacher interviews/focus group, and students' evaluation of the hands-on sessions.

Introduction

Science, technology, engineering, and mathematics jobs in the United States are expected to grow nearly twice as fast as other fields by 2020 [1]. Hence, STEM education is crucial to the ultimate success of our young people. Unfortunately, there is a shortage of both interested and adequately prepared K-12 students in STEM subjects, especially among minority youth and young women [2]. Data shows that among the high school seniors who took the ACT in 2013, only 23 percent expressed interest in STEM majors and fields. Only half of the students who pursue STEM major's graduate with a STEM-related degree [3].

Gaps exist in science and math achievements for students that impacts success in college, especially in engineering programs [4]. The reasons are many, including: lack of authentic learning activities in STEM subjects, inadequate K-12 teacher preparation in math and science content, and poor alignment of K-12 and college curricula. Research has shown that the out-of-school environment advances STEM knowledge and increases interest in STEM-related careers [5]. These delivery models combined with 21st century learning technologies are required to close the opportunity gap that prevents youth from reaching their full potential in fast growing STEM fields.

The engineering-focused STEM outreach program at Elizabeth City State University (ECSU) aligns with existing literature on enhancing student interest and engagement in STEM, particularly in out-of-school settings [5]. Many factors are associated with students' continued participation in STEM disciplines, and ultimately, their pursuit of STEM careers. An important factor is student interest in STEM. Research indicates that hands-on, inquiry-based activities

delivered in informal environments are key factors in helping to develop critical thinking skills and play a significant role in increasing students' interest and engagement in STEM and the likelihood that they will consider science-related occupations [5][6].

Program Implementation

The goal of this NASA supported STEM outreach program is to improve STEM literacy by engaging students in hands-on, inquiry-based learning experiences that supports authentic and experiential learning. The STEM Academy program at ECSU is unique in that it introduces students in rural districts, especially groups traditionally underrepresented in STEM fields, to topics and careers in engineering through a balanced mix of theory, hands-on activities, field trips, and guest speakers. The program offered out-of-school hands-on STEM learning experience for students from middle and high schools. The project target area comprised of 21 counties surrounding ECSU. This region has long suffered the effects of poverty and has lacked the opportunities for most students to encounter the 21st century workplace that is readily accessible in more urban areas of the state. However, with recent growth in hi-tech industry in the region, there now exists the potential to link a K-12 STEM education to this region.

The three key components of the program are:
- Curriculum Enhancement Activities (CEA) – Hands-on, inquiry-based K-12 STEM curricula
  - The outreach program at ECSU utilizes current existing grade appropriate CEAs adopted through well-established NASA STEM curriculum and integrate 3D printing, sensor-based measurement modules, and mini quadcopter UAV design to further enhance the learning experience. Students participating in the program completed a total of thirty-six (36) to Forty (40) hours of hands-on learning per year.

- Aerospace Educational Laboratory (AEL)
  - The AEL consists of fifteen computerized lab stations loaded with CEAs with specific emphasis on the NASA Science and Aeronautics Research Mission Directorates. These lab stations support laboratory modules that are directly related to and augment various STEM subjects and topics.

- Family Connection – parental involvement and informal education
  - The Family Connection is an interactive forum that provides STEM education and parenting or caregiving information to any supportive adult role models who interacts with the students. The goal is to include parents/families as a partner in the planning, design and implementation of the NASA inspired curriculum that support the Next Generation Science Standards and with a strong emphasis on math and science literacy for 21st century learners.

Students participated through Friday Academies, Saturday Academies, and Summer Academies. To meet the annual student participation target, ECSU established partnerships with five school districts (satellite academies), a STEM school on campus, and a Math and Science Education Network (MSEN) program on campus. Teachers/Instructors were provided 25-30 hours of

STEM professional development sessions prior to their delivering curriculum and participating in laboratory experiences with students. Table 1 summarizes the program delivery model.

Table 1: Program Delivery Model

Sessions	Duration	# of Sessions	Grade Level	Activities/Topics
Friday Academy (Spring and Fall)	4 hours	10	Middle Grade only (6-8 grade)	Engineering Design Principle, Robotics, Roller Coaster design, sensors, renewable energy, basic electronic circuits, sensor, rocketry
Saturday Academy (Spring and Fall)	4 hours	10	Middle and High (6-8, 9-12)	Robotics, computer programming, college prep
Summer Academy – Non-Residential	1 week (7 hours/day)	4 camps	Middle and High (6-8, 9-12)	Robotics, Quadcopter design, weather station, sensors, data acquisition, rocketry
Summer Academy – Non-Residential	1 week (7 hours/day)	5 camps	Middle Grade only (6-8 grade)	Engineering Design Principle, Lego Robotics "Mission to Mars" Challenge, Hydroponics
Summer Academy – Residential	1 week (8 hours/day)	2 camps	High School only (9-12 grade)	Quadcopter design, electronics, mobile robotics, rocketry, Arduino microcontrollers, renewable energy, computer programming, College prep

The program team developed curriculum enhancement activities (CEAs) by adopting grade appropriate NASA STEM curriculum. Learning activities integrated 3D printing, sensor-based measurement modules, and mini quadcopter UAV and robotics to further enhance the learning experience. The curriculum supports the Next Generation Science Standards and contained a strong emphasis on math and science literacy for 21st century learners. Students participating in the outreach program completed a total of thirty-six (36) to Forty (40) hours of hands-on experience. Hands-on learning was provided through the AEL, a state-of-the-art laboratory that features collaborative learning environment and equipped with hardware and software to support curriculum enhancement activities. The hands-on activities included 3D Printing, Data/sensor acquisition, mobile Robotics programming, Wind and Solar Energy, Computer Programming (Raspberry PI/Arduino), Roller-coaster design, Wind Tunnel experiments, Science Experiments and more, ready to inspire the next generation of STEM professionals. Wherever appropriate, instruction included covering relevant mathematics and science concepts needed for the hands-on activity. Activities also included demonstration to reinforce STEM topics taught during the week at respective schools where participants came from.

Figure 1 captures some of the activities that were conducted to engage students in an authentic STEM learning experience.

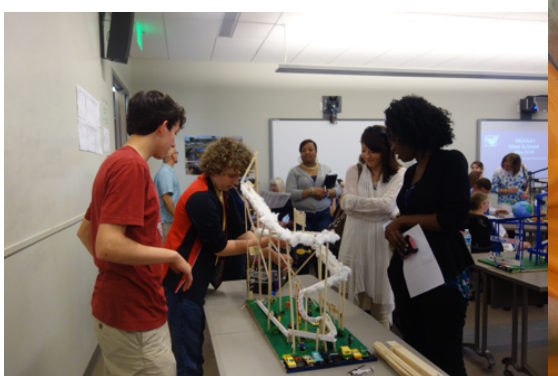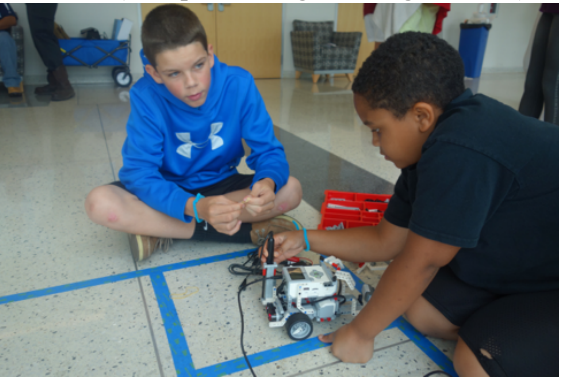*(Mobile robotics building and programming)*

(Quadcopter UAV building)   *(Computer Programming/Arduino)*

(Vernier Mars Challenge using EV3 Lego Mindstorms Robot)

(Roller coaster design showcase)   *(Model Rocket Launch)*

Figure 1: A snapshot of student engagement in STEM activities

Project Evaluation and Results

The project team used multiple evaluation instruments to assess project impact/outcomes. These data collection instruments included: a STEM-CIS Surveys [7], student interviews, focus groups/interviews with teachers, and student evaluation of project staff and hands-on activities. The project team received Institutional Review Board (IRB) approval via an expedited process prior to engaging in project evaluation. The research questions (both implementation and outcomes related) that guided project evaluation are as follows: (i) What are the characteristics of project activities and their participants? (ii) What staff, materials, and project resources are necessary for successful STEM outreach activities? (iii) Did participating students' levels of interest in STEM careers changed significantly between the pre and post 36-40hrs hands-on learning? Table 2 summarizes the evaluation instruments used for data collection.

Table 2: Evaluation Instruments use for Data Collection

Evaluation Instrument	Description	Purpose
STEM Career Interest Survey (STEM-CIS)	Leveraging social cognitive career theory, the STEM-CIS contains four subscales: science, technology, engineering, and mathematics. The STEM-CIS is a 44-item survey that uses a 5-point Likert scale. The survey has been tested and validated in rural, high-poverty districts in the southeastern United States.	Students' self-reported survey to gauge their interest towards science, technology, engineering, and mathematics careers.
Student Interviews	Interviews with three students from each summer academy session. Students were selected to maximize the variation in the sample to include a student (a) who is completing the learning activities with relative ease, (b) who is adequately progressing through the program, and (c) who is having trouble with the activities.	Evaluator and Project personnel inquired about the student's level of interest in mathematics and science, the influence of the program on their mathematics and science motivation, and program highlights and low points.
Interviews/Focus Groups with Teachers	The semi-structured one-hour interview/focus groups during the site visit and at the end of summer session to gather in-depth information about program implementation.	Instructor feedback about curriculum planning and preparation, challenges faced, resource availability and utilization, and professional development experiences.
Learning Experience Evaluation	Students were asked to respond to a set of 8-10 questions pertaining to (i) Class sessions, (ii) instructional quality, and (iii) quality of hands-on activities.	Student feedback gathered on quality of STEM activities and instruction to guide the project team in making necessary improvement in the next cycle.

A total of 523 students participated in the STEM Academy program at ECSU. The participants were comprised of 46.46% male students and 53.53% female students spanning middle and high school grade levels. As shown in Figure 2, overall program participants were comprised of 51.05% middle school and 48.94% high school students. Figure 3 depicts ethnic makeup of program participants. As shown in Figure 3, over 60% of program participants belong to underrepresented groups in STEM fields. The program had 33.08% African-American female participants compared to 23.71% African-American male participants.
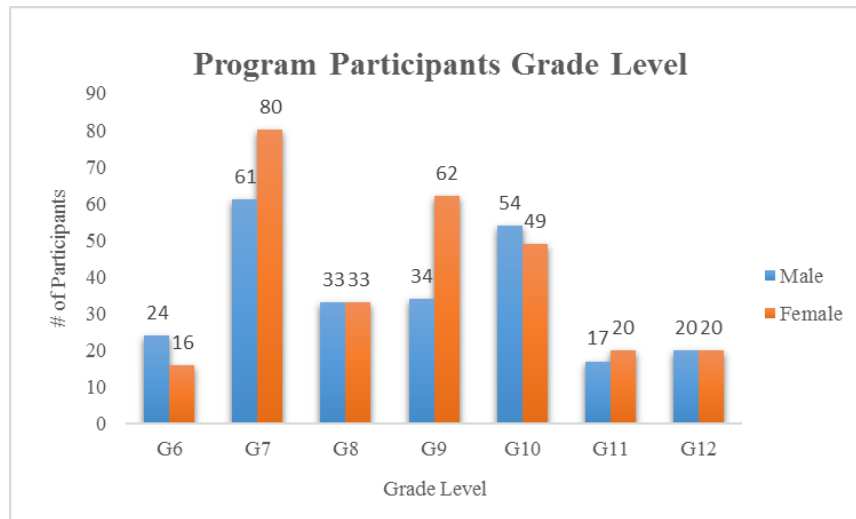

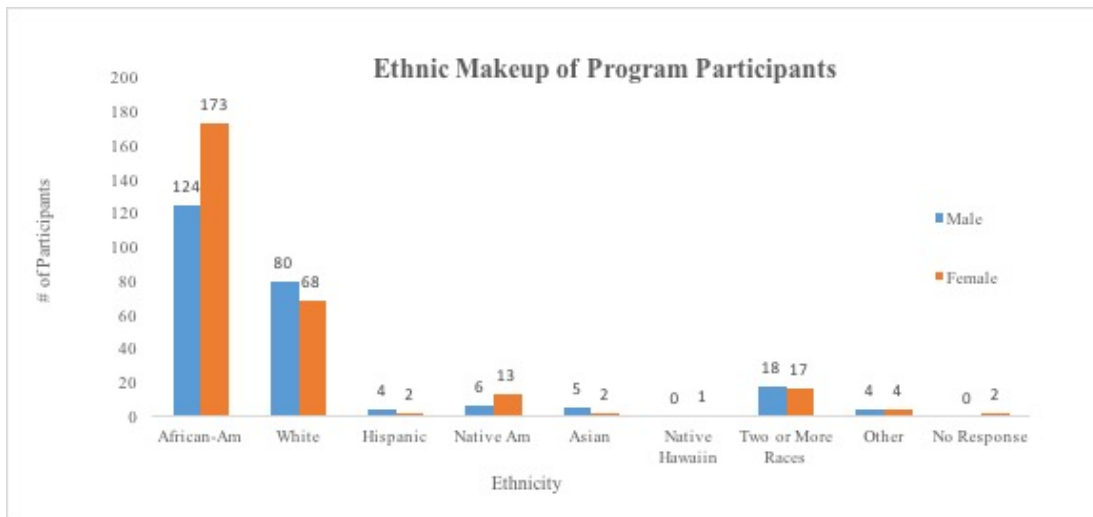Figure 2: Program Participants (Male and Female) By Grade Level

Figure 3: Program Participants (Male and Female) By Ethnicity

The STEM-CIS was administered as a pre- and post-evaluation of the 36-40 hours of STEM learning sessions. The results were analyzed with a paired sample t-test to determine attitude changes within the program participant cohort. Table 3 presents a summary of STEM-CIS pre and post results from the Summer Academy. Sample mean was calculated for all questions (11 each for S, T, E, M) for both pre and post surveys. There was a significant difference in the

scores for the pre-test and the post-test. In each of the STEM categories, there was greater than a 95% confidence level and the results suggest the students' interest increased following the 36-40 hours of instruction in STEM topics.

Table 3: STEM-CIS Survey Results Summary

STEM-CIS Survey Pre and Post Results (N=57)				
STEM-CIS Areas	**Science**	**Technology**	**Engineering**	**Mathematics**
Mean STEM-CIS (Pre)	44.344	46.638	43.776	44.017
Mean STEM-CIS (Post)	46.258	47.759	45.914	45.931
Sample Mean of Difference	1.914	1.12	2.138	1.914
Sample Standard Deviation (SD)	6.079	4.75	5.443	5.117
t-value	2.397	1.797	2.991	2.848
p-value	0.009903	0.03883	0.00205	0.003052

Figure 4 and Figure 5 summarizes overall results of student evaluation pertaining to the quality of classroom activities and instructional support during the program.
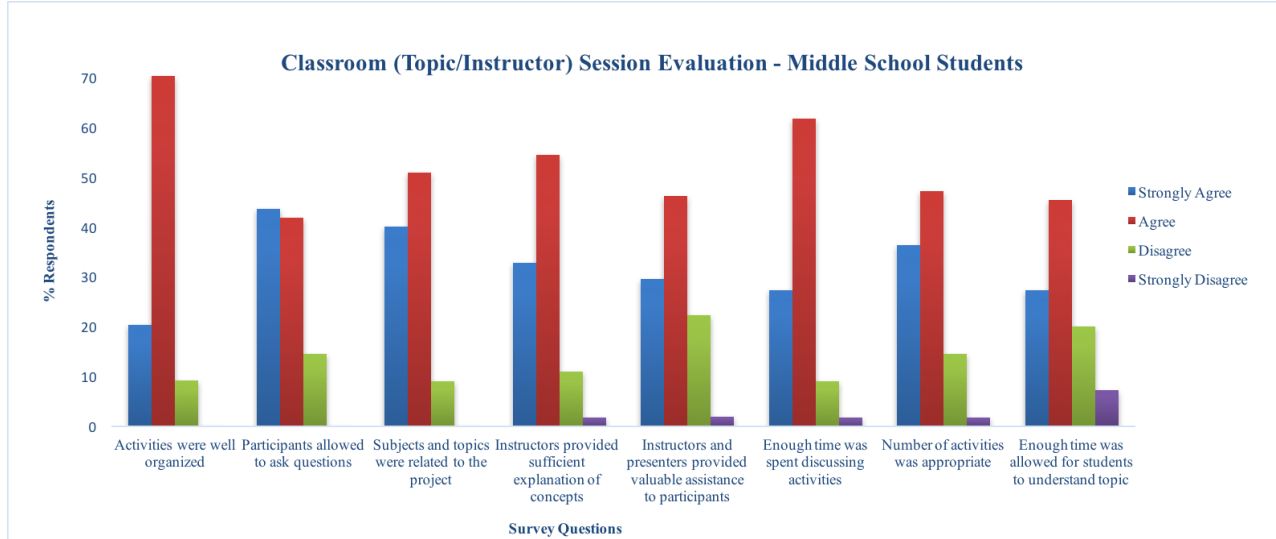

Figure 4: Classroom (Topics/Instruction) Evaluation – Middle School Students (N=134)
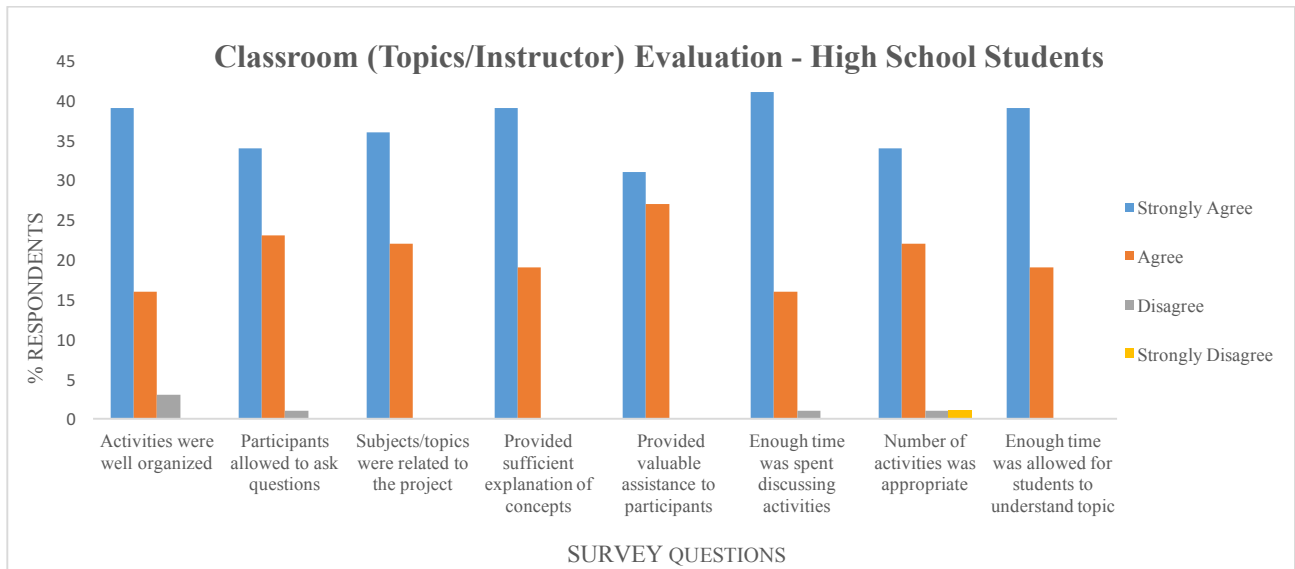
Figure 5: Classroom (Topics/Instruction) Evaluation – High School Students (N=57)

The graphs in Figure 4 to Figure 5 indicate that over 90% of student participants agreed that classroom sessions (topics and instruction) were effective in enhancing their learning experience and exposing them to STEM topics.

The student interviews were conducted by an independent evaluator. The evaluator asked about learning environment, STEM activities, and participation. The classroom and lab space used at ECSU allowed informal group projects and students were encouraged to work within their own and among other teams during their projects. Although many students felt ill-prepared to build their Unmanned Aircraft Vehicle (UAV) or Lego Robotic vehicle at the beginning of the program, they expressed pride at the end as they determined they felt confident in their ability to pursue engineering design projects. Introverted students were routinely encouraged by others to participate and were praised when they expressed their ideas during projects and team assignments. All students interviewed by evaluators expressed a positive learning experience during the camp and said all lessons, field trips, and lectures were beneficial.

Student comments included:

- *"I was scared at first, there were a lot of pieces, but as we sent step-by-step, it became much easier."*

- *"Although we were unable to fly our quadcopter, it was a lot of fun learning how they are made and programmed."*

- *"It was really fun here. Hope you do this camp again next year so more kids can learn about aerospace, robotics, etc."*

- *"The academy should be longer. Add more coding sessions with arduino."*

- *"Really enjoyed the rocket topic and making one."*

-"We need longer breaks to relax our mind and talk about what we did."

Evaluation for the program culminated with interviews and focus group with instructors. All instructors commented their students had a positive and effective learning experience and felt they received sufficient support from the program leadership at ECSU through frequent onsite visits and daily conference calls.

Some areas of concern included late delivery of curriculum and supplies. Although ECSU did hold some professional development sessions, satellite academy instructors did not have timely access to the supplies that were to be used during the summer session. All instructors (middle school summer camps) commented that they should stay at their home school during summer sessions because middle school students need consistency. It was difficult for the students to get used to different teachers and it detracted from teaching time to prepare students in satellite camps for the project demonstration and presentation on ECSU campus. In addition to the instability of the rotating camp schedule, it was noted that ECSU should deploy two teachers with classroom experience to satellite camps instead of "teaching interns" with little observable experience with school children.

Some of the recommended actions for next year are as follows:

1. Use Dimensions of Success (DoS) Observation tool to evaluate student engagement for the year round and summer non-residential academies. Limit use of STEM-CIS instrument to summer residential academies.
2. Conduct overall program quality evaluation (topics, instructor/staff, field trips, and guest speakers) once at the completion of 36 or 40hrs of STEM learning instead of evaluating every session.
3. Teacher to stay at their satellite sites instead of rotating between middle school satellite camps. Provide additional training for pre-service teachers who will be assisting lead teachers.
4. Develop home-based project activities for family connection component of the project.
5. Integrate an Advanced Career (AC) model developed by the Southern Regional Education Board (SREB). Pilot test the AC curriculum focused on Aerospace Engineering with high school students. In addition, offer high school juniors and seniors to receive dual credits.
6. Reduce the number of topics covered and focus on limited activities geared towards one theme. In case of middle school, avoid projects involving review of detailed guidelines.

Conclusion

In this paper, implementation and evaluation of an engineering-focused STEM outreach program was discussed. The goal of this NASA supported program is to improve STEM literacy in rural and underserved regions of the state. Three key components of the program are Curriculum Enhancement Activities, Aerospace Education Lab, and Family Connection. A total of 523 students participated through ten Friday Academy sessions, ten Saturday Academy sessions, and eleven Summer Academies (2 residential and 9 non-residential). STEM topics included engineering design principle, robotics, roller coaster design, sensors, basic electronic circuits,

renewable energy (solar and wind), sensor and data logging, rocketry, computer programming, quadcopter theory and design, and Arduino microcontrollers. Project team used multiple instruments to evaluate the program. Evaluation data shows that 36-40 hours of hands-on STEM activities resulted in significant gains in student interest in STEM careers. The program activities were successful as determined by the positive student interviews, focus groups and student evaluations of project staff. Some areas of concern were identified and will be addressed during the next program offering. During next year, project team plans to introduce Advanced Career (AC) curriculum developed by the Southern Regional Education Board (SREB) and use Dimensions of Success (DoS) Observation tool to evaluate out-of-school learning environment, student STEM engagement, and student participation.

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