Three ERCs and a National Network Node: Assessing Engineering Outcomes for Middle School Students Across a Joint Outreach Event

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Introduction

The aim of both the National Science Foundation (NSF) Engineering Research Center (ERC) Program and the National Nanotechnology Coordinated Infrastructure (NNCI) is to achieve transformative change by integrating engineering research and education with technological innovation within areas at the frontiers of science and engineering. ERC and NNCI sites across the nation study and innovate within their technical area using similar structures and implementation strategies that include the coordination of educational endeavors. These efforts are intended to support students, teachers, and postdoctoral scholars in research labs; provide educational outreach to engage the community; encourage the participation of underrepresented populations; and partner with industry to achieve their vision [1-2].

Some of the challenges associated with these educational programs include organization, available manpower, and evaluation. Representatives from three ERCs and one NNCI Network Node, in collaboration with their external evaluation teams, have established a consortium to better address these challenges. The assembled consortium is uniquely situated to cooperatively tackle these challenges because they are co-located at the same university. The members have taken advantage of their proximity by meeting regularly to establish joint educational and research efforts, resource sharing, and consistent evaluation tools.

This paper focuses on a single joint outreach effort undertaken by the consortium in collaboration with a former Research Experiences for Teachers (RET) intern. Efforts by the consortium included providing and evaluating interactive activities to the former RET intern's middle school students during a field trip to the university.

Background

There continues to be a significant disconnect between properly prepared graduates and the predicted millions of jobs to be filled in the science, technology, engineering, and mathematics (STEM) fields [4]. Research on developing the engineering workforce often indicates the need for early exposure to the field in order to increase awareness and interest in careers related to STEM [3]. The result is a growing emphasis on developing K-12 instructional materials focused on engineering concepts to stimulate interest in related careers [5]. The degree to which these materials impact interest must be examined, which is why it is important to design quality assessments for measuring student interest in STEM fields and the proficiency gained by participation [6].

Arizona State University is the lead institution for two NSF-funded Engineering Research Centers (ERCs) (Center for Bio-mediated and Bio-inspired Geotechnics (CBBG) and Quantum Energy and Sustainable Solar Technologies (QESST)), a partner university for a third ERC (Nanotechnology Enabled Water Treatment (NEWT)), and home to an NSF-funded Nanotechnology Network Node, (Nanotechnology Collaborative Infrastructure Southwest (NCI-SW)). Each entity promotes informal learning opportunities through similar research experiences and outreach events. The education leadership team and evaluators from these NSF-funded centers have formed a consortium to share information and resources in an effort to leverage the combined expertise and resources.

Consortium team members submitted, and were recently awarded, an NSF ERC Supplement to fund these collaborative efforts. The major focus of this supplement was to address the challenge of evaluating and standardizing instruments developed to measure the impact of education and diversity efforts. As stated in Section 4.6 of the NSF ERC Best Practice Manual [7], “NSF recognizes the importance of assessing the impact of all ERC University and Precollege Education programs and the General Outreach to involve precollege students in the ERC activities that it supports.” NSF has also requested an increase in assessment rigor of outreach events and follow-up [8]. The overall task of educational program evaluation is typically taken on by each ERC in isolation even though NSF strongly encourages instrument sharing among ERCs [7]. The consortium is attempting to change the paradigm by joining forces to collaborate and learn from each other. This paper shares one of the first efforts of the consortium to offer a joint outreach event assessed by shared evaluation tools.

Outreach Event

A one-day outreach event for 110 seventh grade students was organized for a former RET intern from CBBG by the Education Director for CBBG in collaboration with the education leaders of QESST, NEWT, and NCI-SW. The former CBBG RET intern provided a starting point for identifying objectives related to his previously created lesson during his summer research experience. The teacher met several times with the CBBG Education Director over a two-month period to discuss the objectives of the fieldtrip and aligning them to the middle school curriculum Next Generation Science Standards (NGSS) [9].

Sustainability was identified as a common denominator across the ERC consortium that would align with performance expectations specific to Middle School Earth and Space Sciences (MS-ESS). Per objective MS-ESS 3-1 [10], the consortium sought to generate identification of “challenges presented by the uneven distribution of Earth’s mineral, energy, and groundwater resources”; explanations of how science and engineering practices are utilized to remedy these challenges; and discussion of evidence that this uneven distribution is “the result of past and current geoscience processes.” The consortium sought to “design a method for monitoring and minimizing a human impact on the environment” using scientific principles based on the objective MS-ESS 3-3 [11].

This on-campus event was facilitated by the education leaders, Student Leadership Councils, and evaluation teams from CBBG, QESST, NEWT, and NCI-SW. Seven faculty members, fifteen graduate students, and one former RET intern collaborated in the planning process for the outreach event. The identified NGSS performance expectations were shared with the facilitators who worked to develop activities that would align with each objective. Each center or network node provided a 20-minute activity framed by their technical focus that aligned with the standards and provided information pertinent to the social and economic fabric of Arizona. Facilitators provided interactive and experiential activities as well as lecture-based presentations that explored biogeotechnics, water filtration, nanotechnology, and solar energy.

Biogeotechnics (led by CBBG)

The activity presented by CBBG on the topic of biogeotechnics incorporated discussion between groups of students and a complementary demonstration. The first discussion, accompanied by the demonstration, examined current practices in place to mitigate wind erosion. Facilitators discussed sustainable methods of reducing dust emissions, with consideration for the environment and the preservation of essential resources. The second discussion focused on nature-inspired solutions to mitigate liquefaction caused by earthquakes and sustainable remedies to other environmental problems, including the use of sustainable materials for construction purposes.

Solar Energy (led by QESST)

The presentation by QESST educated students about solar energy. Students divided into two subgroups and participated in two activities. The first activity examined the effect of outdoor temperatures on the efficiency of solar panels, supplemented by a demonstration exhibiting a solar panel placed on dry ice. The second activity examined the composition of solar cells, supplemented by a demonstration displaying various types of materials used.

Water Filtration (led by NEWT)

The activity presented by NEWT sought to educate students about de-facto water use and water treatment using nano-blocks. A presentation was used to address the cycling of water between towns downstream from one another, emphasizing the importance of water purification prior to recycling. Nano-blocks were used to introduce a method for the removal of contaminants from water, while minimizing material use for purification.

Nanotechnology (led by NCI-SW)

The activity presented by NCI-SW included a presentation about nanotechnology that covered fundamentals of computer composition. Students participated in a window tour of the Arizona State University NanoFab and learned about specialized equipment used to construct computer chips.

Research Questions

Data collected from participants in the outreach event provided insights into the following research questions:

- RQ1. What concepts did participating middle school students learn from the outreach event?
- RQ2. Did participating middle school students learn something interesting from the outreach event?
- RQ3. To what degree did the outreach event influence participating middle school student interest in pursuing a STEM career?
- RQ4. What lasting impact did the outreach event experience have on participating middle school students?

Methods

Participants

The event was held for 110 seventh grade science students from populations traditionally underrepresented in STEM. A total of 94 students (85% response rate) completed the assessment tools on the day of the event. This sample of students included 44 (46.8%) identified males and 39 (41.5%) identified female. The remaining 11 student participants (11.7%) did not disclose their gender identities.

Data Collection & Analysis

Student participants' knowledge and interest were assessed during the outreach event to assess concepts learned (RQ1), content interest (RQ2), and career interest (RQ3). The lasting impact of the outreach event (RQ4) was assessed by two follow-up activities, one with the teacher and one with the students.

Concepts Learned

Assessment of what students learned from each of the presented activities was performed by asking students: *Please write something you learned after visiting each of the projects in today's field trip.* Students were given a reflection worksheet at the first activity they attended and were instructed to respond to the same prompt after completing each activity. Student open-ended responses were analyzed using a thematic data analysis approach [12-13].

Content Interest

Student interest toward the outreach event activities was gathered by asking students to respond to a single question on a poster board: *Did you learning something interesting from this activity?* A poster board was mounted on the wall adjacent to each activity (Figure 1). The poster boards included three response options selected by students using corresponding emoji stickers: 1) yes, definitely (green sticker), 2) sort of (yellow sticker), or 3) no, not really (red sticker). Students placed the emoji sticker that reflected their response on the poster board before going to the next activity.

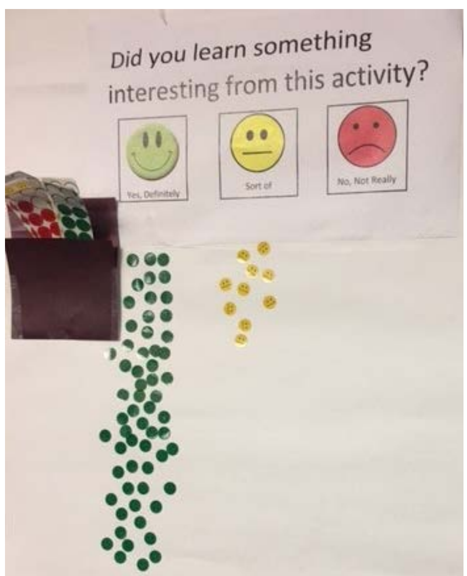

Figure 1. Example of content interest poster board.

Career Interest

The immediate influence of the outreach activity on students' interest in pursuing a career in a STEM field was gathered using a multiple-choice question: *After participating in this field trip, what is your level of interest in pursuing a career as a scientist or engineer?* Students were asked to circle the response best describing their interest from the following options: *I am more interested now, I am the same as I was before the field trip,* or *I am less interested now*. Once the students rotated through all four activities, they were instructed to complete this final question on the reflection sheet, and return the worksheet to a member of the research team.

Lasting Impact
A set of follow-up post-assessments were conducted following the outreach event to examine lasting impact. The delay in data collection purposefully allowed time for teacher preparation, lesson implementation, and student instruction back in the classroom. A follow-up interview with the middle school teacher/former RET intern was conducted two months after the event to examine perceived student preparation for the outreach event, connections made between classroom instruction and the outreach event (before and after), perceived student value from the experience, and feedback on how to improve future outreach events for additional teachers and students. The interview was audio recorded, transcribed, and coded. A follow-up survey with the middle school students was disseminated five months following the event to assess student perceptions of the different concepts learned during the outreach event, application of concepts in their science classroom, and interest in learning more about content presented during the outreach event.

Results

Concepts Learned

Biogeotechnics (CBBG Project). Student responses (n = 94) directly following this activity referenced aspects of earthquakes, sand, or soil (Table 1). The largest number of students described what they learned regarding the composition of earthquakes (13.8%). In addition, a larger number of students reported an enhanced understanding of the destructive capabilities of earthquakes (11.7%). Additionally, eight students (8.5%) discussed preventative measures used to prevent dust and soil from rising. Several students (2.3%) specifically referenced the demonstrations, which aided in their understanding of the composition of earthquakes, and of the role of a substance's density in causing it to rise or sink in the case of an earthquake. A subset of these students described the demonstrations as "cool," referring to "when the sand went up and the house sank" and "when the sand shook and went down and the two balls came up."

Table 1
Emergent student reflection themes from the biogeotechnics (CBBG Project) activity

Theme	**Example Quote(s)**	**% of students**
Composition of earthquakes	"in an earthquake, tunnels come up from the ground because of the light fluids in the ground." "I learned that air in the tunnels cause it to move up during an earthquake."	13.8
Destructive capabilities of earthquakes	"I learned [what] earthquake[s] do to homes." "I learned about gravity and how earthquakes can sink objects."	11.7
Preventative measures to prevent dust and soil from rising (referring to carbon spray)	"keep the dirt intact" "prevent houses from being buried in the ground during an earthquake" "make the ground stronger so the buildings stay there"	8.5
Chemical composition of sand and soil	"sand is very solid" "there is microbes in the soil" "soil can rise to go up" "soil is made of fertilizer"	7.4
Role of air pressure during earthquakes	"…the air in the ground pushes the particles together like cement." "…that the air in the tunnels cause it to move up during an earthquake."	5.3
Importance of a firm foundation beneath a building	"I learned that to build you need to have a great foundation because if you don't your 'house' would fall and would sink." "houses can fall over if there's just sand and not anything else."	3.2
Buoyancy effect	"when earthquakes happen things underground will float and things [in] the soil will sink."	2.1

Note: Some student answers were coded to include multiple themes.

Solar Energy (QESST Project). Student responses (n = 94) directly following this activity reported learning about basic concepts of solar energy, including what it is, how it works, its practical uses in society, and how solar panels are made (Table 2). The largest percentage of students (30.9%) reported their understanding of solar energy and the interaction with temperature. Others reported on how solar energy is powered by the sun (16%) and how society uses solar energy (11.7%). Just over 10% of students reported on the mechanics of solar panels, i.e., how they are made and how they work.

Table 2
Emergent student reflection themes from the solar energy (QESST Project) activity

Theme	**Example Quote(s)**	**% of students**
Solar energy functions more effectively in cooler temperatures	"…cold gives more energy" "…electrons aren't running into each other" "…the hot electrons don't go all over the place"	30.9
The role of the sun in solar energy	"solar energy is powered by light." "sunlight converts into electricity."	16.0
Societal uses of solar energy	"I learned that solar energy is from the sun and gives electricity to houses." "I learned that in 10 years solar panels will be normal." "we are gonna have clothes that have solar panels and you could charge your phone."	11.7
How solar panels are made	"[solar panels] are made in different shapes and sizes." "[solar panels] can be as thin as a paper."	5.3
How solar panels work	"produc[ing] electrons" "preserv[ing] heat" "mak[ing] electricity"	5.3

Note: Some student answers were coded to include multiple themes.

Water Filtration (NEWT Project). Students responses (n = 94) directly following this activity discussed water transfer and reuse, the use of water waste plants, the importance of cleaning and treating recycled water, and the use of nanoparticles for removing contaminants from water. Almost a quarter of students (24.5%) referenced the visual demonstration using wooden blocks and pom-poms as an aid to their understanding of the water filtration process (Table 3).

Table 3
Emergent student reflection themes from the water filtration (NEWT Project) activity

Theme	**Example Quote(s)**	**% of Students**
Water transfer and reuse	General discussion around the flow of water between cities.	40.4
Use of nanoparticles to remove contaminates from water	"That the smaller ones with more surface area cleans the water better" "Using smaller blocks helps get bacteria out more. It helps more than one big block."	24.5
Water treatment and cleaning (water waste plants and water treatment processes)	"…we use waste water treatment to treat our water when someone uses it." "…chemicals are used to make [water] drinkable." "The water has to be cleaned before drinking; it has to be cleaned 4 times."	18.1

Note: Some student answers were coded to include multiple themes.

Nanotechnology (NCI-SW Project). Common areas of knowledge reported by students (n = 94) directly following this activity included the size (20.2%) and cost (14.9%) of microchips, effects of lighting on microchips (25.5%), and the importance of cleanliness in the laboratory (13.8%) (Table 4).

Table 4
Emergent student reflection themes from the nanotechnology (NCI-SW Project) activity

Theme	**Example Quote(s)**	**% of Students**
Definition of nanotechnology	General discussion on small size	20.2
Effects of lighting on microchips	"White light harms microchips." "White light affects the chemicals used in the lab." "The windows are tinted so the white light doesn't affect the chemicals." "I learned that the room is yellow because the chemicals are light sensitive." "I learned that we need [yellow light] in the science room so that it won't affect the chemicals."	25.5
Cost of computer chips	Cited prices ranging from $100,000 to $1,000,000	14.9
Cleanliness in lab is important due to chip sensitivity	"I learned that one particle of dust can damage computer chips." "It has to be super clean so nothing can affect the process." "Always have your entire body covered head to toe so it doesn't affect the microchips."	13.8

Note: Some student answers were coded to include multiple themes.

Content Interest

Results from the student interest posters are presented in Figure 2. Response rates ranged from 73-83%. The majority of students indicated "Yes, Definitely" for all four activities.

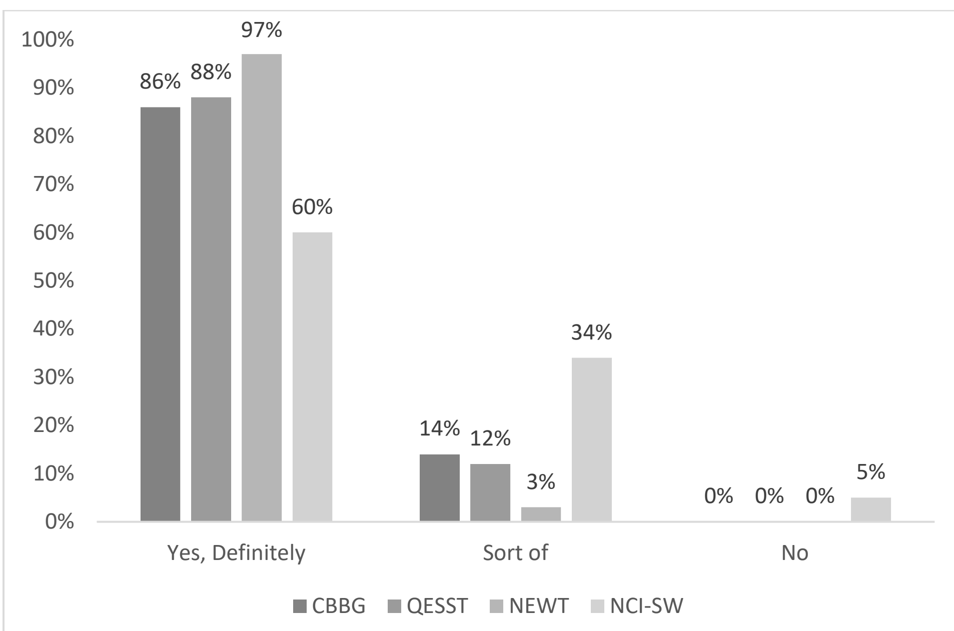

Figure 2. Student interest in the content presented during each outreach event activity.

Career Interest

Responses (n = 74) to the final reflection question examining the degree in which the outreach event instilled interest among students to pursue a career as a scientist or engineer in the future are presented in Figure 3. Nearly three quarters of respondents (73.0%) reported that they are "more interested now" than they were prior to the outreach event.

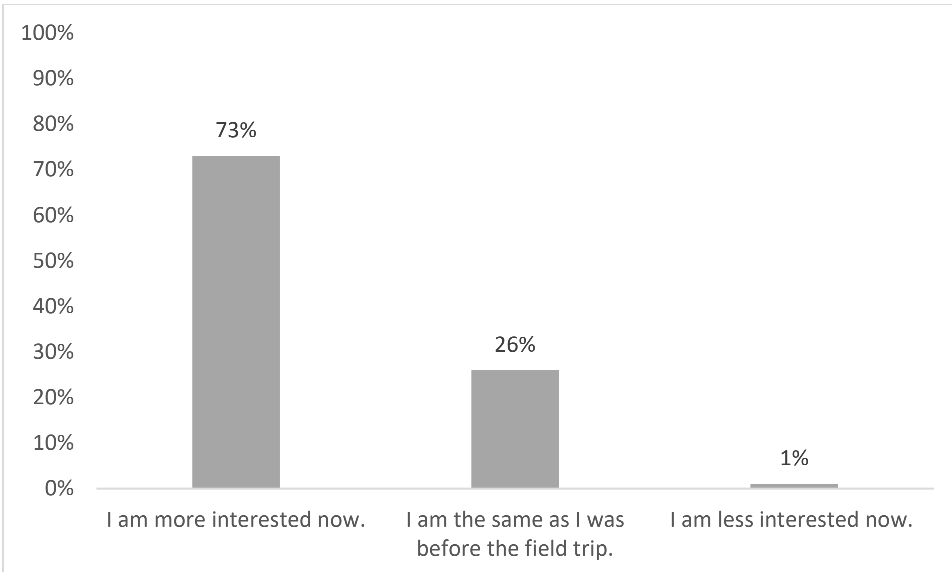

Figure 3. Student interest in pursuing a STEM career following the outreach event.

Lasting Impact

Teacher Interview. The teacher reported that he spoke with his students about the importance of using STEM to solve real world problems prior to the outreach event. He explained this to students by reiterating that, "...as a STEM School, we [are] really interested in learning about how other people in the real world are using science, technology, engineering and math to help solve real world problems so we want to pay attention to the problems that the presenters showed to us and their solutions and how they developed their idea[s] and how they went to the design thinking process to get there."

The teacher then stated that he made connections between the outreach event and his lessons both before and after the outreach event. The teacher noted that as part of the seventh grade Earth Science curriculum, he was covering rocks and minerals and how these materials have properties that can be widely applied and used. He believed students held a "surface level understanding of that [earth materials]" prior to the outreach event. They explored these ideas further following the event and "solidified those connections." For example, the teacher discussed, "…us[ing] the different properties of different materials to make and manufacture different things like solar panels and to come up with different solutions." He went on to note additional connections, stating, "… [W]e're actually studying earthquakes so we'll make those connections to the field trip again and what we did with the CBBG to study liquefaction and applying different solutions chemically to soil to prevent liquefaction," and "I have a lesson I built with the CBBG to bring that learning to students I'll be implementing next week." One of the primary benefits of the outreach event was the "breadth of different engineering applications that connects to a lot of the science in small ways so, like, when that comes up in the curriculum, we have some prior knowledge that we can apply to what we are learning."

Three additional ways that the teacher described the outreach event as valuable for students was 1) opportunity, 2) understanding of the engineering process, and 3) real world application of STEM. First, he indicated the significance of this opportunity for underserved students, commenting that "being a Title I school that is a predominantly underrepresented population of individuals in the scientific community, just getting the opportunity to go to a college campus, and to see the diverse number of people from diverse backgrounds who are participating in engineering, makes that a very real thing for students." Second, he talked about how the trip was valuable for students to learn that engineering is an iterative process. He stated, "They actually got to see multiple generations of a prototype and actually see that engineering process kind of come to life then realize that, hey we can learn from our mistakes and that it is okay to make mistakes." Finally, he described how students were better able to see real world applications of engineering, which increased their interest in a subject that is not always relatable to 12 and 13-year olds (e.g., rocks and minerals). He explained that, "when [7th grade students] actually have that experience, and they see how that applies in the real world, it definitely kind of lifts their ears and makes them pay attention a little bit more to what we're learning. 'Cause now they see the purpose behind it. It's not just something in a book that they've been asked to learn about by the state."

The teacher's primary recommendation for improving the outreach event experience moving forward was more time for questions and answers. The teacher noted how helpful it was for students to be able to ask questions and discuss topics with the faculty and graduate student presenters. He also noted that there were unforeseen logistical time restrictions due to weather and transportation delays which minimized the time that students had to interact with the presenters and ask questions. Preparing a plan for mitigating these types of issues where applicable may provide better opportunities for students to fully engage with the programming. Overall, the teacher saw great value in this experience for students and concluded with, "I thought it was a really well-organized, well-conducted event, and we really appreciate the opportunity to be able to come and to learn."

Student Follow-up Survey. A total of 77 students completed the follow-up survey (70% response rate). The fixed item response results indicate that 95% of the students agreed or strongly agreed that they learned a lot of new scientific concepts during the outreach event and 90% agreed or strongly agreed that they were looking forward to learning more about those concepts in their science class this year (Figure 4).

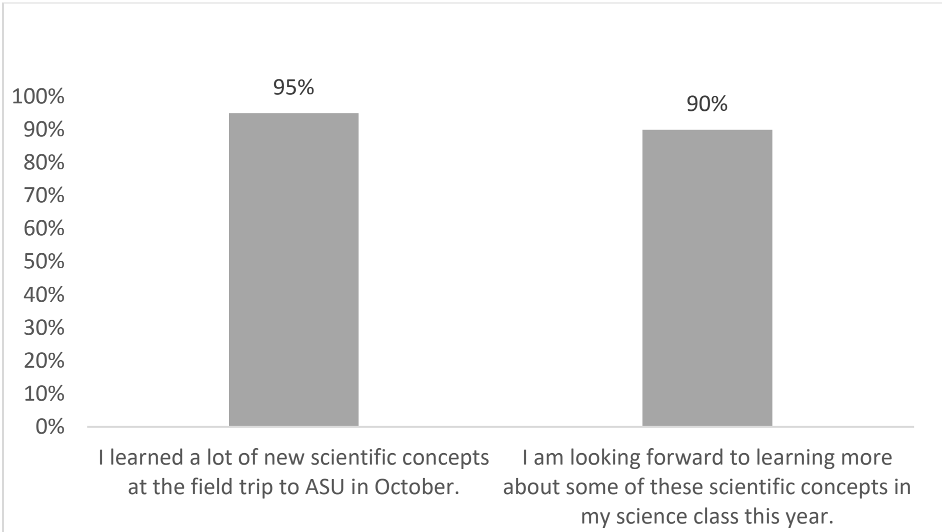

Figure 4. *Student perceived lasting impact from the outreach event.*

Additional open-ended questions examined how students are currently using the information learned from the outreach event in their science class and what they remember as being the most important thing they learned during the outreach event. Students responses to information learned and used in their science class was general knowledge of earthquakes (24%) and information on the formation of earthquakes (20%) (Table 5). The majority (71%) of students reported using information in their class that was connected to earthquakes in some way, which is likely due to the fact that the science teacher was a former RET participant for CBBG and developed a related lesson.

Table 5

Emergent themes from the following survey question: How are you currently using the information learned from the field trip in your science class?

Theme	**Example Quote(s)**	**% of Students**
General earthquake knowledge	"We did a model about earthquakes and learned about them."	24%
Formation of earthquakes	"We use the information when we learned about earthquakes and why they happen."	20%
Liquefaction	"We used that information when we were learning about earthquakes and liquefaction."	9%
Destructive capabilities of earthquakes and ways to prevent damage	"During the field trip our group talked about earthquakes and how they affect us and what they are trying to do to cause less damage."	9%
Earth Structure	"We used it by finding how the structure of earth works."	9%
Solar energy/panels	"I am currently using the information I learned on the field trip by learning about the Sun which connects to Solar Panels."	9%
General knowledge	"I'm using information in my science class."	9%

Note: Some student answers were coded to include multiple themes.

Student responses to the most important thing learned from the outreach event were classified into four themes: 1) solar energy (23%), 2) water, (22%) 3) earthquakes (18%), and 4) microchips (15%) (Table 6). These themes align with the four activities at the outreach event demonstrating a high-level of recall from the outreach event.

Table 6
Emergent themes from the following survey question: What is the most important thing you learned from the field trip at ASU?

Theme	**Example Quote(s)**	**% of Students**
Solar energy	"I believe the most important thing I learned was about the solar panels, because they are going to be the new and best way of getting electricity without harming the environment." "The most important thing I learned was about Solar panels because it gives us a clean energy source."	23%
Water	"The most important thing I learn was how they clean the water to make it safe for us." "Reusing water might be the most important to me now."	22%
Earthquakes	"The most important thing I learned was the lesson about trying to stop earthquakes from making structures fail." "How we can make houses stronger against earthquakes."	18%
Microchips	"The most important thing I learned was how microchips were made." "I learned how they make Microchips. It's like a little lab and not one piece of dirt can infect the Microchip."	15%

Conclusions & Future Work

The examination of an outreach event offered to 110 middle school students provided insights into content learned, interest in STEM content, growing interest in STEM careers, and lasting impacts. Results indicate increased interest and knowledge gained by the student participants even after the event concluded. Data collected from the students' teacher suggest the event had a real and lasting impact on these students. The follow-up student survey data corroborated the teacher's insights revealing that high percentages of students reported learning new scientific concepts and were interested in learning more about those concepts. Students also reported that they were using information from the outreach event in their science classrooms, mostly in ways that were related to earthquakes. This did not deter them from recognizing the importance of a wide array of topics learned from the outreach event (Table 6).

This overall educational effort was a comprehensive initial investigation led by a consortium of NSF ERCs and a Nano-Network Node. Additional studies will continue to leverage the educational programs of these entities to grow the body of knowledge pertaining to the overall educational impact of these collaborative efforts.

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