From Project Mercury to Planet Mars

Summative Evaluation

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EXECUTIVE SUMMARY

The Museum of Science, Boston led the *From Project Mercury to Planet Mars: Introducing Engineering and Inspiring Youth through Humanity's Greatest Adventure* project (FPMPM) as a way to produce and share high-quality informal engineering education opportunities about the topic of human space travel to Mars. This project, which spanned from fall 2016 through fall 2018, was funded through a grant from NASA (Grant Number NNX16AM21G). The grant involved the creation of two products that address human space travel to Mars: an immersive full-dome planetarium show and a hands-on engineering design challenge.

To evaluate the grant work, the Research & Evaluation Department at the Museum of Science, Boston conducted a summative evaluation study, which is summarized in this report. The summative evaluation focused on assessing the extent to which the design challenge and planetarium show met their goals for the target audience of underserved youth in grades five through nine. To gather data, more than 100 youth from the Boys and Girls Clubs of Boston viewed the planetarium show and participated in the design challenge. These youth completed surveys and interviews after each activity, and were observed while engaging in the design challenge.

The evaluation questions and key findings about the planetarium show included:

- *What do participants learn from the planetarium show?* Participants reported learning more about the technology and engineering involved in human space travel.
- *To what extent does experiencing the show increase participants' opinions that human space exploration is important?* Most of the middle school youth already agreed that human space exploration was important before the show, and a few reported an increased sense of the importance afterwards. Many shared that human space exploration is important because it leads to new learning or because future humans might live in space.
- *To what extent does experiencing the show increase participants' interest in future activities and careers in engineering and science?* After viewing the show, middle school youth reported slight increases in interest related to activities and careers about science and engineering. Most youth found engineering for space exploration to be exciting, but viewing the planetarium show did not have a sizable effect on middle school youth's interest in activities about human space exploration.

For the design challenge, the evaluation questions and key findings were:

- *To what extent does experiencing the activity increase participants' opinions that human space exploration is important?* Participants often agreed that human space exploration is important, although there were no significant increases after participating in the activity.
- *To what extent does experiencing the activity increase participants' interest in future activities and careers in engineering and science?* After the activity, participants reported significantly greater interest in learning about human space exploration at school, taking college classes in science or engineering, and becoming a scientist or engineer.
- *To what extent do participants engage in the engineering design process?* About two-thirds of participants engaged in each of the four steps of the engineering design process.
- *To what extent do participants feel they did something like what an engineer does?* 73% of participants agreed or strongly agreed they did something like what an engineer does.

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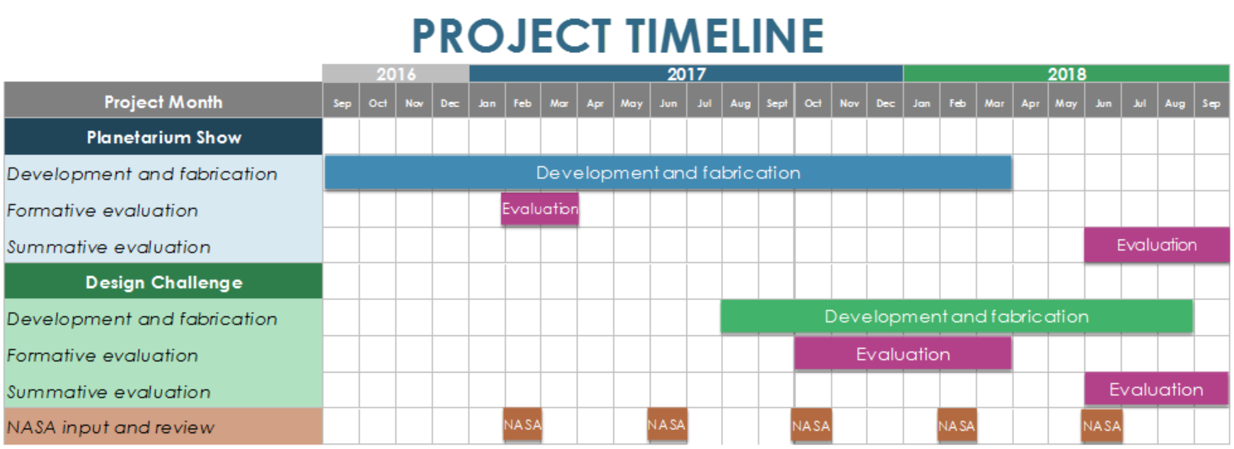
I. INTRODUCTION

1.1 Project Overview

The Museum of Science, Boston led the *From Project Mercury to Planet Mars: Introducing Engineering and Inspiring Youth through Humanity's Greatest Adventure* project (FPMPM) as a way to produce and share high-quality informal engineering education opportunities about human space travel to Mars. Journeying to Mars and back is a proposition that is easily understandable and compelling for nontechnical audiences, acting as a strong hook for those who have minimal background in science or technology. However, it is a massive technological challenge that demands the collaboration of numerous scientific and engineering disciplines. In the past, this idea seemed like science fiction. Thanks to groundbreaking work from the National Aeronautics and Space Administration (NASA) and commercial industry, it is quickly becoming a feasible reality, and the next generation of scientists and engineers will contribute to it. The upcoming need for science, technology, engineering, and math (STEM) professionals who will bring diverse new ideas to this challenge makes the present moment a critical time to engage the public in learning about human space travel to Mars.

This project, which spanned from fall 2016 through fall 2018, was funded through a grant from NASA (Grant Number NNX16AM21G), through the Competitive Program for Science Museums, Planetariums, and NASA Visitor Centers Plus Other Opportunities (CP4SMPVC+) solicitation. The grant involved the creation of two products that address human space travel to Mars: an immersive full-dome planetarium show, and a hands-on engineering design challenge. Creating these two products involved strong institutional partnerships around the country to create innovative new educational opportunities that would engage and inspire a broad audience of learners about the exciting science and engineering work that NASA and others are pursuing, to achieve the goal of getting humans to Mars.

FIGURE 1. Timeline of project activities.



1.2 Project deliverables

The Museum of Science, Boston created two primary deliverables as part of the FPMPM grant:

1) ***Destination Mars: The New Frontier*, a full-dome planetarium show**: This 30-minute planetarium show focuses on current and planned missions to Mars that NASA and other commercial partners are undertaking. It highlights the science and technology from projects such as the International Space Station (ISS), the Space Launch System (SLS), the Orion spacecraft, and Exploration Mission 1 (EM-1). Thanks in part to images and 3D models shared by NASA, and access to NASA facilities during the development phases of the show, viewers experience an immersive journey around Mars dunes, the ISS, Kennedy Space Center and its Vehicle Assembly Building, and a Mars concept vehicle.
2) ***Mission: Mars*, a hands-on engineering design challenge**: This activity uses human habitation on Mars as an inspirational context in which museum visitors undertake an engineering challenge. As if they were designing a surface habitat for Mars, participants use an assortment of nylon and rubber pieces to create the largest possible habitat design that can collapse to fit inside a "lander" test unit, and self-deploy while remaining fully enclosed. The activity encourages visitors to work through the engineering design process of designing, building, and testing a prototype solution. Visitors test their design by placing their prototype in a lander that lifts off, allowing the platform underneath to rotate as the testing unit measures the deployed design's height and width.

Along with each of these products, the team developed an educator guide. The guide for the planetarium show is written for teachers who wish to integrate this show into their curriculum, likely when bringing students to view the show as part of a field trip. It provides extensive background information on the show's content and topics, and offers additional resources for teachers to use with students in their classrooms. The guide for the design challenge is written for other institutions beyond the Museum of Science that wish to lead this activity at their own sites. It includes logistical information, set-up procedures, a materials list, activity goals, best practices, tips for facilitating the activity with visitors, and guiding questions to frame the activity for participants.

1.3 Project partnerships

The Museum of Science, Boston worked with a variety of partners to produce and disseminate high-quality products as part of this grant. In addition to providing the funding that supported the grant work, NASA was a vital contributor of expertise and resources. NASA staff shared information about ongoing efforts, provided visual materials for use in the planetarium show, hosted Museum of Science staff members on tours of NASA sites, and provided feedback about project materials as they were being developed. All of this helped to ensure that the educational materials reflect accurate and up-to-date information about the science and technology associated with human space flight.

The NASA sites that supported the project included:

- Houston Space Center

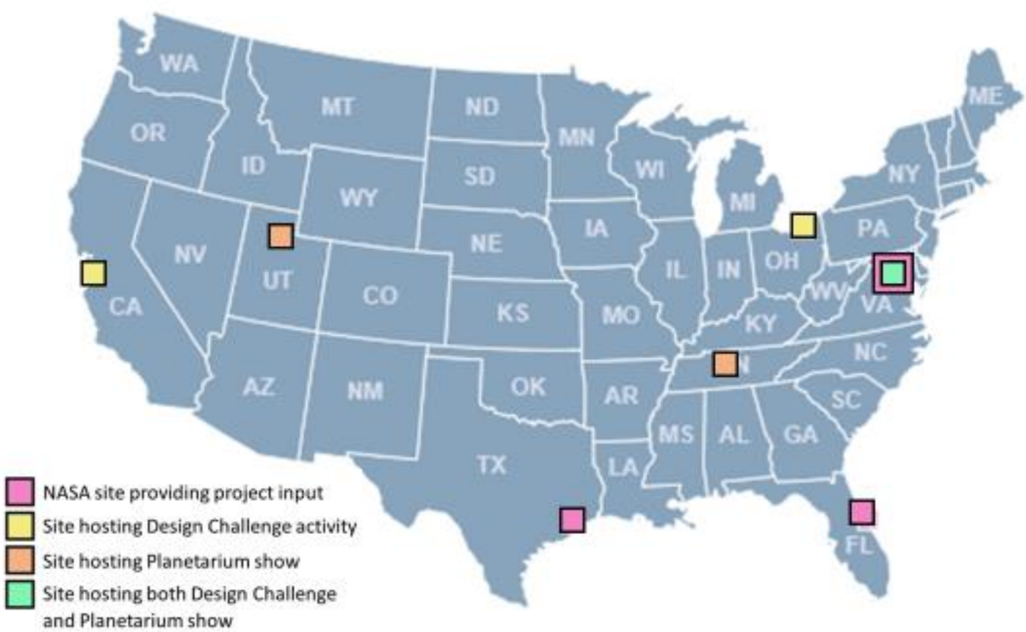
- Kennedy Space Center
- Johnson Space Center
- NASA Headquarters

In addition to NASA, the project team worked with a group of well-recognized ISE partners across the country, who were chosen for their expertise in creating and leading planetarium or design challenge activities, their interest in sharing the design challenge or planetarium show with their audiences, and for the diversity of the audiences that they serve. At the beginning of the project, members of these partner sites attended a two-day, in-person meeting with Museum of Science staff to participate in a collaborative planning session about the planetarium show's vision and content. Representatives from the sites also participated in interviews about the design challenge to inform the technical requirements and educational direction of that work. At the end of the project, the two deliverables were shared with the sites so they could be distributed and used across the US.

As shown in the map below, the ISE partner sites included:

- Clark Planetarium (UT)
- Smithsonian's National Air and Space Museum (DC)
- Great Lakes Science Center (OH)
- Sudekum Planetarium at the Adventure Science Center (TN)
- The Tech Museum of Innovation (CA)

FIGURE 2. Map of project partners.



1.4 Project audience

From Project Mercury to Planet Mars: Introducing Engineering and Inspiring Youth through Humanity's Greatest Adventure project (FPMPM) materials were designed to reach a large and diverse audience, particularly students who are traditionally underserved in science, technology, engineering, and mathematics (STEM) education. According to a National Science Foundation (NSF) report (2017), these groups include women and girls, persons with disabilities, and Blacks or African Americans, Hispanics or Latinxs, and American Indians or Alaska Natives.

The Museum of Science, Boston is a field-wide leader in engaging underserved audiences, with highlights including its recognized work as a leader in Universal Design for Learning; its Engineering is Elementary curriculum that has reached over nine million students; its development of gender-equitable participatory design challenges; and more. As mentioned above, project partners were also selected for their ability to reach underserved audiences. Special preference was given to sites that have large reach among rural and inner city communities.

In developing the planetarium show and design challenge, the project team focused on middle school students in grades five through nine. This age group was selected because studies have shown that to encourage students from underserved demographics to stay in the STEM pipeline, it is important to reach them with STEM programming before they develop the stereotypes that discourage them from pursuing science and technology in their education and career paths (Legewie, J., & DiPrete, T., 2011; Jacobs-Priebe, L., & Crowley, K., 2013). Opportunities to engage in informal science activities, which include the immersive technology of a fulldome planetarium show and the tactile stimulation of a hands-on design challenge, are often less available to underserved youth (Lin & Schunn, 2016). This project sought to provide these exciting and engaging opportunities to all types of young learners, and worked with educators to ensure that the content was aligned with relevant standards in formal education for the middle grades.

1.5 Project goals

FPMPM deliverables were designed to address two Education Priorities from the 2015-2017 NASA Education Implementation Plan: STEM Engagement and Institutional Engagement. To support STEM Engagement, or the effort to offer learning experiences that connect learners to NASA resources, the project worked with NASA to ensure that the content of the programming accurately reflected the agency's mission and technological achievements. In terms of Institutional Engagement, or the effort to increase the capacity of ISE organizations to incorporate NASA content, a set of strong partnerships with NASA and with other informal education institutions across the country helped the project team develop innovative programming and extend its reach, as described above.

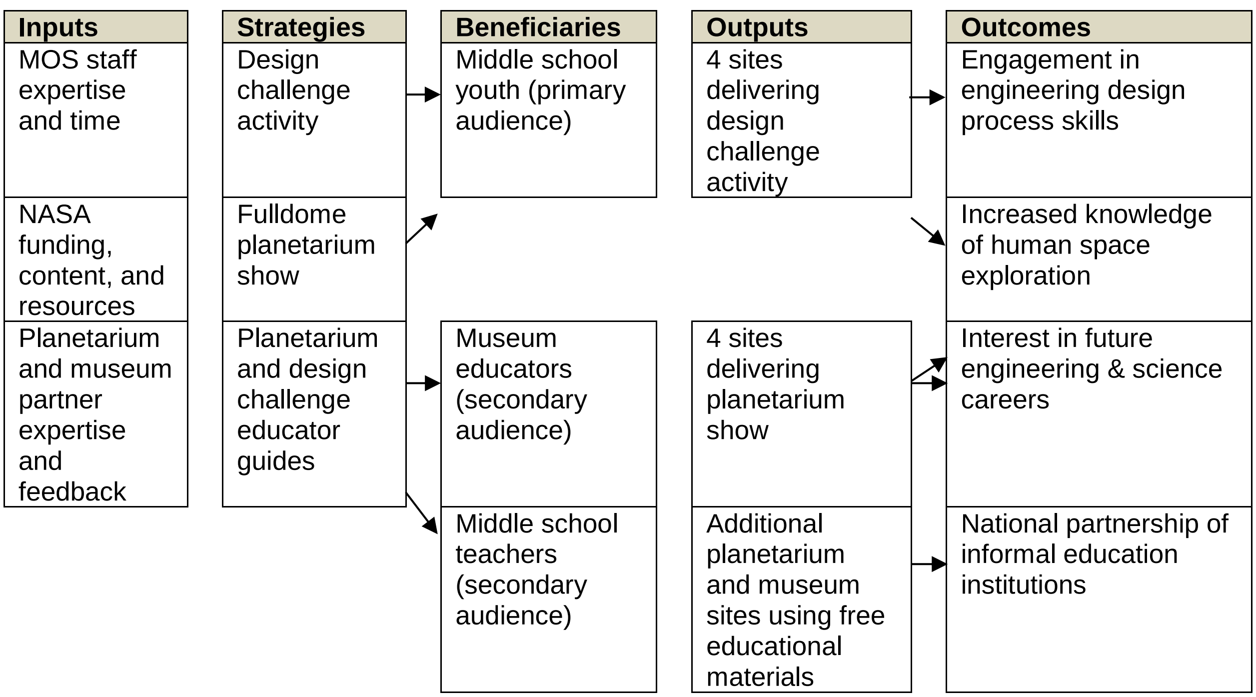
The specific project goals for FPMPM were to:

1. Increase student and public awareness of the critical importance of human space exploration, and the engineering feats that must be achieved to realize our vision of

sending astronauts to Mars.
2. Inspire the next generation of engineers and scientists through the development and distribution of a fulldome planetarium show and related educational materials, for use by middle-grade educators, that share the importance of a mission to Mars, highlight the dramatic technological challenges involved, and share the nature and excitement of the breakthrough engineering that will get us there.
3. Actively engage middle-grade students in the engineering design process and in engineering habits of mind, through the development of engineering design challenges related to human space missions.
4. Create a strong national partnership of leading informal education institutions, focused on bringing authentic STEM education experiences to young people traditionally underserved in science and engineering activities.

The logic model shown below (Figure 3) situates these goals in the context of the larger project activities.

Figure 3. FPMPM Logic Model



1.6 Evaluation overview

The Research and Evaluation Department at the Museum of Science, Boston led the evaluation efforts for FPMPM. All of the staff developing the project's deliverables were part of the Museum's Education Division, and report to PI Annette Sawyer. The Research & Evaluation Department had the necessary independence to conduct this evaluation because it is housed within the Strategic Initiatives Division under the leadership of Senior Vice President Lawrence Bell.

Evaluation for FPMPM consisted of formative and summative studies. For the formative evaluation of the design challenge activity, data were collected to inform the activity, helping to ensure that it would be engaging and educational for its target audience (middle school students), and that it could be easily implemented at additional sites by other museum educators. There were three rounds of formative evaluation on the design challenge activity: one round of interviews with museum educators at the partner sites that would host the design challenge, and two iterative rounds of observation, and interviews with visitors who interacted with prototypes of the design challenge activity as it was being developed.

For the planetarium show, formative evaluation sought to ensure that the content connected to middle school students' classroom practices and was engaging for participants. There were four rounds of testing. First, evaluators conducted a focus group with middle school teachers who reviewed the script and provided feedback. Next, there was a round of interviews with museum visitors about what topics were most interesting, and what they already knew about the topics. Finally, evaluators gathered two rounds of interviews with museum visitors, where they were shown a description of the show and potential titles for it. Then, they were asked what was most compelling about the description, and which title best matched the description.[1]

This report focuses on the summative evaluation testing that occurred after the design challenge and planetarium show were in their near-final forms. The summative evaluation focused on assessing the extent to which the design challenge and planetarium show met their goals for their public audience of underserved youth in grades five through nine. Goal four, which relates to professional audiences, is assessed through documentation of project partnerships and is compiled in project reporting outside of this evaluation report. The evaluation questions that guided the summative evaluation and provide the outline for the report include the following:

Destination Mars: The New Frontier planetarium show:

1. What do participants learn from the show about the technical challenges and breakthrough engineering associated with human space exploration?
2. To what extent does experiencing the show increase participants' opinions that human space exploration is important?
3. To what extent does experiencing the show increase participants' interest in future activities and careers in engineering and science?

Mission: Mars design challenge:

1. To what extent does experiencing the activity increase participants' opinions that human space exploration is important?

[1] The formative evaluation reports that resulted from these rounds of testing were created for an internal audience of the team members who would use the data to make decisions about the development of the project deliverables. As such, the reports are not published publically. However, they can be made available upon request. Inquiries should be directed to researcheval@mos.org.

2. To what extent does experiencing the activity increase participants' interest in future activities and careers in engineering and science?
3. To what extent do participants engage in the engineering design process?
4. To what extent do participants identify that they are engaged in an activity that is like what an engineer does?

II. METHODS

2.1 Methods overview

The summative evaluation used a mixed methods approach, gathering both quantitative and qualitative data from each participant. This approach is a rich, multi-faceted way to answer the evaluation questions; the qualitative data support the quantitative data with descriptive context and the quantitative data assess the broad applicability of the qualitative results. Additionally, the evaluators used multiple methods (including survey, observation, and interview) about each project deliverable. This mixed methods triangulation design is valuable because it "compares the results, and then uses those findings to see whether they validate each other" (Fraenkel & Wallen, 2006, p.443). Table 1 shares a summary of the methods used in the summative evaluation and details about each instrument are below. All instruments are provided in the appendix of this report.

TABLE 1. Summary of Summative Evaluation Methods

Deliverable	Method	Brief description	Sample size
Planetarium show	Survey	Demographic information and quantitative questions about interest, learning, and the importance of space exploration	94 middle school students
Planetarium show	Flash interview	Brief, open-ended questions about learning and the importance of space exploration	62 middle school students
Design Challenge	Survey	Demographic information and quantitative questions about engagement and the importance of space exploration	81 middle school students and 18 museum visitors
Design Challenge	Flash interview	Brief, open-ended questions about interest and engagement	41 middle school students
Design Challenge	Observation	Checklist that tracks evidence of engagement in the engineering design process of design, build, test, and improve	37 middle school students and 25 museum visitors

To ensure that the summative evaluation sample was representative of the project's target audience of underserved youth in grades five through nine, the Museum of Science and its evaluation team partnered with the Boys and Girls Clubs of Boston to gather the summative evaluation data. On June 13, 157 youth visited the Museum and were randomly assigned to a schedule during which they rotated through the planetarium show, hands-on design challenge, and dinner. This ensured that equivalent numbers of youth saw the planetarium show before doing the design challenge, and did the design challenge before seeing the planetarium show. All students who participated in the evaluation had brought signed forms from their parents or legal guardians. Youth were also informed verbally, and in writing on the surveys, that their participation was voluntary and anonymous.

Youth completed the planetarium survey right at the end of the planetarium show. While they were still sitting in their seats, planetarium staff gave all consenting participants pencils and surveys, which were printed on heavy cardstock so that they could be completed without a hard writing surface. The lights were adjusted so students could see the surveys, and the students were directed to fill out their surveys before they left. Following the completion of the planetarium survey, youth brought their paper surveys out of the planetarium space and handed them to an evaluator, who stored the surveys in a sealed envelope. When the student handed in the survey, the evaluator would ask them the two short flash interview questions.

Data collection for the design challenge followed a similar pattern. Evaluators used a continuous random sampling approach to select target individuals for observation, and followed the target individuals for the duration of their experience. For the survey, evaluators used census sampling—asking every student with consent to complete a survey when she or he finished the activity. Similarly, all students who handed in a survey were then invited to take part in the two-question flash interview.

Almost all of the data for the summative evaluation was successfully collected on the one-night event with the Boys and Girls Clubs. There was one caveat to data collection during the event: dwell time was likely influenced by the schedule that the students were assigned to by the evaluators As such, to gather more authentic observation data, evaluators collected 25 additional observations following the main data collection event. For these observations, evaluators used a continuous random sampling approach to select target individuals who appeared to be within the target age range of grades five to nine. Because there was no direct interaction with these individuals, no additional demographic information is available.

2.2 Planetarium survey

The survey about the planetarium show asked a series of questions about each of the evaluation questions for the show. The main structure of the survey was a retrospective pre-post item design. This type of questioning involves collecting data from participants after they experience the activity in question (in this case, after watching the planetarium show) and asking them to report how they felt about certain topics *before* the show and how they feel now, *after* the show. Retrospective pre-post questions have been shown to be a valuable evaluation approach for informal learning experiences, because they are effective at addressing participants' tendency to overestimate their knowledge of a subject before they participate in an intervention (Rennie & Johnson, 2007). The rating scale for each question was a four-point Likert scale.

The survey for the planetarium show included retrospective questions about three topics: 1) the youth's interest in taking part in future STEM activities, 2) their knowledge about the science and technology involved in human space travel to Mars, and 3) their sense of the importance of human space exploration. For each of these topics, the survey included between two and four items. In addition, the survey asked youth to report their age and gender in an open-response format.

2.3 Planetarium flash interview

To gather qualitative information about the planetarium show, evaluators conducted brief "flash interviews" as students left the show. The interview consisted of two questions: "What, if anything, did you learn about human space exploration by watching this show?" and "What, if anything, do you think is important about space exploration?" Interviews were conducted individually or in small groups, depending on whom the students were with as they left the planetarium. If the interview included multiple people, each person's response was recorded separately. This flash interview approach has been shown to be effective at getting a relatively large number of responses in a short amount of time, and is particularly useful when collecting data about an experience that finishes for a large group at the same time. This technique has been used for multiple recent summative evaluation studies at the Museum of Science, Boston (Barth, Paneto, Anderson, Kollmann, Todd, & Nelson, 2018; Cahill, Mesiti, Paneto, Pfeifle, & Todd, 2018).

2.4 Design challenge survey

The survey about the design challenge was similar to the planetarium survey. The design challenge survey asked a series of questions about each of the evaluation questions for the activity. Like the planetarium survey, the main structure was a retrospective pre-post item design. The design challenge survey also included one set of non-retrospective statements, for which youth indicated their level of disagreement or agreement.

The survey for the design challenge included retrospective questions about three topics: 1) youth's interest in taking part in future STEM activities, 2) their perception of the challenges involved in engineering for human space exploration, and 3) their sense of the importance of human space exploration. For each of these topics, the survey included between two and four items. In addition, the survey asked youth to report their age and gender in an open-response format.

Youth completed this survey as they finished the design challenge. Activity facilitators and researchers helped pass out cardstock surveys and golf pencils as youth cleaned up their materials. All students who participated in the evaluation had brought signed forms from their parents. The surveys also included consent language indicating that participation was optional and anonymous. Some of these surveys were collected from general public visitor groups in the weeks following the primary data collection event.

2.5 Design challenge flash interview

As the youth returned their completed surveys, researchers invited them to answer two short interview questions. The first question was, "What, if anything, did you do in this activity that was like what an engineer does?" The second question was, "What, if anything, do you feel is exciting about human space exploration?" Interviewers spoke to one or two youths simultaneously and recorded their answers separately. Not every youth who completed the design challenge activity was interviewed.

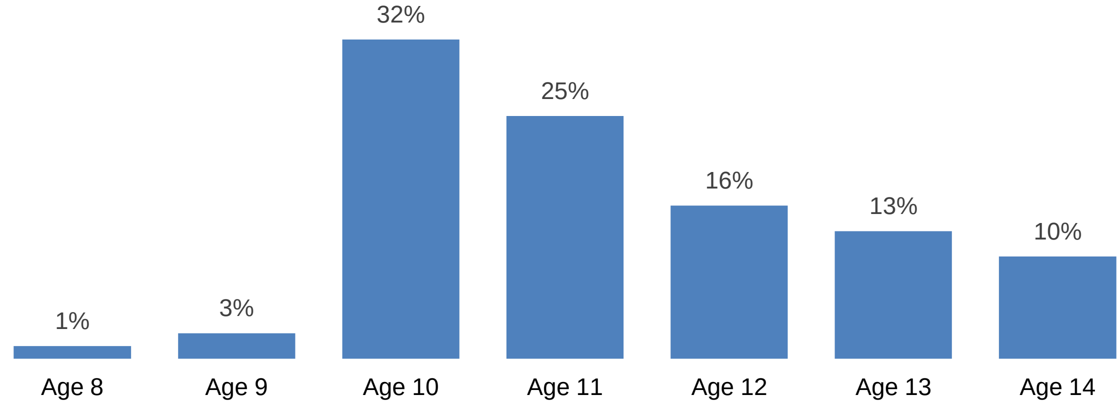
2.6 Design challenge observation

Researchers also observed youth while they used the design challenge activity. The observation sheet focused on looking for behaviors that are part of the engineering design process, conceptualized in this project as: 1) Ask/Imagine/Plan, 2) Create/Build, 3) Test, and 4) Improve. Behaviors related to these steps appeared on the observation sheet as a checklist, with the items adapted from prior research and evaluation of engineering design challenges (Auster & Lindgren-Streicher, 2013). Additionally, researchers timed youth with a stopwatch from the time they approached the facilitator's table for an introduction until they cleaned up their design to understand how long they engaged in the activity. Researchers also kept track of how many times the youths tested their designs and took open notes about what the youths said and did.

2.7 Sample description and data collection information

For the Boys and Girls Clubs participants, each survey asked respondents to indicate their age and gender. The data show that 56% of respondents were female, and that the ages of the respondents ranged from 8 to 14. The average age was 11, and the age composition is broken down in Figure 4. Because demographic data can be sensitive, tedious, and difficult for youth participants to understand, evaluators did not gather additional demographics on the individual level. However, the Boys and Girls Clubs of Boston provided aggregate demographics of their Club members: 56% identify as female, 86% are racial or ethnic minorities, and 58% are low-income.

FIGURE 4. Age composition of Boys and Girls Clubs of Boston respondents. (n=77)



2.8 Data analysis

Analyzing the mixed methods data from this summative evaluation necessitated both quantitative and qualitative analysis approaches. Quantitative data analysis included a mix of descriptive and inferential statistics. Descriptive statistics included counts, percentages, and averages. Where appropriate, inferential tests were used to assess differences within the sample (for example, differences between retrospective pre- and post-responses). Many of these tests were non-parametric because of the relatively small subsample sizes and the fact that the data were not always normally distributed. In these cases, evaluators used Wilcoxon Signed Ranks Tests to determine whether there were differences between two related samples of ordinal data (e.g., pre- and post- scores on a Likert scale of "Strongly Disagree" to "Strongly Agree"), and calculated r to measure effect sizes. Small effect sizes are defined as an absolute value of r between 0.1 and 0.3, medium as between 0.3 and 0.5, and large as anything greater than 0.5. Two-way ANOVA analyses were used to test for main and interaction effects between age and gender. Statistically significant differences were defined as those for which the statistical test result had a p-value below 0.05.

Qualitative data analysis included a combination of deductive and inductive coding. Deductive coding is a process of looking for established factors in the data, whereas inductive coding involves reviewing the data and identifying the most frequent themes (Patton, 2002). For this project, evaluators began with a list of criteria for project goals and first coded for evidence of the respondent meeting these goals. For instance, in the qualitative interview responses to the question "What, if anything, did you do in this activity that was like what an engineer does?" evaluators first looked for evidence of each of the stages of the engineering design process: plan, create, test, and improve. For responses that did not fit in any of these categories, the evaluators used an inductive process of summarizing the remaining themes of the data. The coding process involved multiple evaluators. Each question was coded by one evaluator, and then 10% of the responses were independently coded and checked by a second evaluator. If there were disagreements, the two discussed the coding and came to an agreement. The inter-rater reliability was 70-100%, depending on the question.

2.9 Limitations

As with any study, the data from this evaluation have a number of limitations. One primary factor to consider is that the products for this project were created for a national audience of underserved youth from grades five to nine, but were evaluated with a small subset of that audience. The partnership with the Boys and Girls Clubs of Boston ensured that the youth who provided data did fit within the target audience, but they are not representative of all youth who are underrepresented in STEM. All lived in the Boston area, were inner city youth, and attended the Museum of Science, Boston. They did not represent youth visitors to any of the other partner sites that will host project materials.

Another consideration is that there could possibly be order effects that cannot be detected, confounding the data. Because of the structure of the event, half of the respondents to either survey or interview had already experienced the other project deliverable. Thus, it is conceivable that any gains in learning, interest, or sense of importance about human space travel may have a plateau effect after the first experience, leaving little room for further improvement for the second. The data collection protocols did not allow evaluators to analyze any order effects that might have occurred.

A third issue is that some of the respondents may not have taken the data collection seriously. A number of the responses to the demographic questions suggest that students were giving flippant answers. For instance, one individual indicated that her or his gender was "Martian," and some of the reported ages were well outside the range of who we knew to be attending the event. When these responses pop up, it is unclear the extent to which the rest of the data may or may not reflect students' true perspectives. Taking a survey could potentially feel like a test, which stands at odds to the fun opportunities to be had at the Museum. As such, students may have rushed to finish without reading things carefully. The timing of this event at the end of the school year may have also contributed, with students perhaps feeling eager to be in summer mode, and reluctant to complete data collection efforts that felt academic.

Another consideration is that middle school youth are subject to peer pressure. The flash interviews were conducted within the context of the groups in which students were naturally visiting. This has the benefit of helping students feel comfortable talking to evaluators, but middle school students may be especially susceptible to adjusting their answer to be socially acceptable for their peers.

Finally, aside from considerations to do with the sample and data collection process, it is important to note that the data collection took place before the design of the planetarium show and design challenge were completely finished. All of the key elements were in place, but the planetarium show's final narration and score had not been recorded, and there were editing tasks still left to be done. Some of the show's final gloss was missing, with flatter voices and more jolting transitions than would be present in the final version, which may have taken from the overall impression of professionalism, even if all of the content matched the final version. For the design challenge, summative testing helped the project team identify some physical changes that needed to be made to allow for greater durability of materials. Therefore, some of the pieces were changed out after the data collection, and improvements were made to the unit that tested participants’ design and measured their output. Thus, it is possible that the findings would have been slightly different if data had been collected from the final versions of the deliverables. However, no changes are directly relevant to any of the evaluation questions, and the early data collection was necessary to complete the evaluation before the end of the project.

III. PLANETARIUM SHOW FINDINGS

This section shares data about how the planetarium show impacted middle school youth's learning and attitudes about space exploration. Data were collected through a retrospective pre-post survey that asked respondents to: 1) indicate their interest in follow-up activities about space exploration or science and engineering, and 2) rate their level of agreement about the importance of efforts to progress exploration to Mars and their attitudes towards space exploration. Participants also responded to two interview questions after the planetarium show regarding what they learned from viewing the show, and what they thought was important about space exploration.

Findings in this section will be organized by the following evaluation questions and findings:

- **3.1** What do participants learn from the show about the technical challenges and breakthrough engineering associated with human space exploration?
  Although participants came in with high levels of knowledge, they reported learning more about the technology and engineering involved in human space travel from the planetarium show.

- **3.2** To what extent does experiencing the show increase participants' opinions that human space exploration is important?
  Although most of the middle school youth agreed that human space exploration was important before viewing the show, some reported an increased sense of its importance after the show, because it leads to new learning or because humans might need to live on another planet someday.

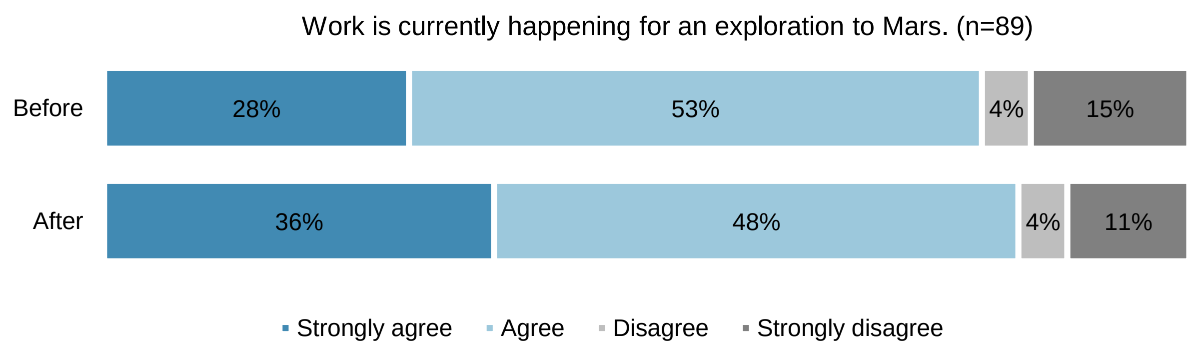
- **3.3** To what extent does experiencing the show increase participants' interest in future activities and careers in engineering and science?
  Middle school youth reported coming in with high levels of excitement for engineering for space exploration, but the planetarium show did not appear to have a sizable effect on their interest in activities about human space exploration. Nevertheless, middle school youth indicated small increases in interest for long-term activities about science and engineering after viewing the planetarium show.

3.1 Although participants came in with high levels of knowledge, they reported learning more about the technology and engineering involved in human space travel from the planetarium show.

A primary educational goal of the planetarium show was that participants would learn about the technical challenges and breakthroughs in engineering that are associated with human space exploration. The survey included two retrospective pre-post questions about this goal: 1) Work is happening for an exploration to Mars and 2) Technology is changing to support an exploration to Mars. Youth provided agreement responses to these questions using a four-point scale ranging from "strongly disagree" to "strongly agree." Youth were also asked an interview question about what they learned related to human space exploration.

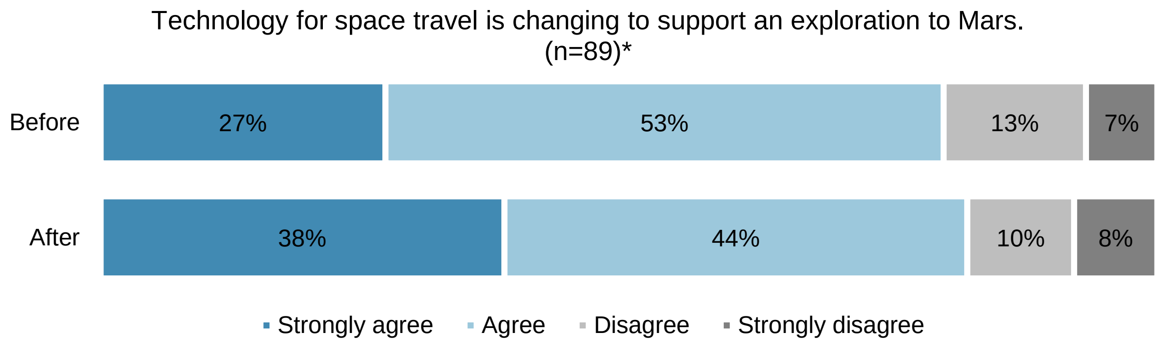
Although there were no statistically significant differences between retrospective pre- and post- responses, the middle school youth who saw the planetarium show reported some increased learning about this topic. Prior to seeing the show, 81% of 89 youth respondents "agreed" or "strongly agreed" that work is currently happening for an exploration to Mars. After viewing the planetarium show, there was a slight increase in the percentage of youth who agreed or strongly agreed with this statement, with this percentage rising to 84% afterwards (n=89). This included an increase from 28% before the show to 36% of youth who reported that they "strongly agreed," after the show. Overall, 21% of students increased their ratings for this question from pre- to post-. Interview data also showed evidence of youth understanding that work is happening for Mars exploration, with one-third of youth (34%) providing facts from the show about human space travel or elaborating on the need for human survival strategies on Mars. These data are summarized in Figure 5.

FIGURE 5. Ratings of agreement that work is happening for Mars exploration.



While youth did not show significant changes in their understanding that work is happening to allow for exploration of Mars, they did show gains in understanding that technology is changing to support this exploration. Before viewing the planetarium show, most youth (80% of n=89) agreed or strongly agreed with a second retrospective pre-post survey question about whether technology for space travel is changing to support an exploration to Mars. In comparing the retrospective pre- and post- data, a Wilcoxon signed-rank test indicated a statistically significant increase from pre- to post- responses with a small effect size (Z=-2.01, p=.04, n=89, r=-0.21). This change is illustrated in Figure 6, which shows an increase from 27% to 38% in the "strongly agree" category, and a minimal increase from 80% before the show to 82% after the show in the combined "agree" and "strongly agree" categories (n=89). Overall, 23% of students increased their ratings for this question from pre- to post-. To further support this claim, interview data conveyed that almost one-quarter of youth (22%) discussed the engineering or building required to do space travel, often mentioning rockets, satellites, or the International Space Station. These data are summarized in Table 2.

FIGURE 6. Ratings of agreement that space travel technology is changing to support Mars exploration.



After watching the planetarium show, youth were asked the following interview question: "What, if anything, did you learn about human space exploration from viewing this show?" The chart below (Table 2) details the type of information that youth reported that they learned from their experience, and shares example quotations (n=58). As previously noted, one-third of youth (34%) shared that human space travel is happening, sometimes providing facts from the show about human space travel or the need for human survival strategies on Mars, and almost one-quarter of youth (22%) discussed the engineering or building required to do space travel, often mentioning rockets, satellites, or the International Space Station. Additionally, some youth noted that space exploration is challenging, detailing that this endeavor is risky and time consuming (22%). Some of these respondents added that they felt that humans would be successful in achieving their goals for space exploration. Some youth shared a fact about Mars (17%), particularly that there used to be water on Mars, or discussed general interest or understanding of importance about human space exploration (14%).

TABLE 2. Flash interview responses pertaining to learning about human space exploration. "What, if anything, did you learn about human space exploration by watching this show?"

Code about learning	# of responses (n=58)	% of responses (n=58)	Example quotation
Evidence that human space travel is happening, including facts about human space travel and human survival	20	34%	*I learned that humans might be able to go to Mars and live on Mars.* *They need to find a way to get food, water, shelter, survival.*
Evidence of engineering for space travel, including building or creating, how long it takes, how to build spaceships, or mention of satellites	13	22%	*They're building space vehicles to Mars. The rocket is about a football field (long).*
Space exploration is challenging	13	22%	*They are taking time and it's a difficult process, but they won't stop no matter what.*
Facts about Mars	10	17%	*Three billion years ago there was water and ice on Mars and now it's very dry.*
Evidence of importance, interest, or excitement	8	14%	*People are excited to go to Mars.*
I don't know	5	9%	*I forgot.*
Other	5	9%	*Ready for anything.*

Note: Responses can be coded into multiple categories

These data suggest that participants came into this event with high levels of knowledge regarding the work happening for Mars exploration, as well as an understanding that technology is changing to support Mars exploration. This initial high level of agreement may not be surprising since Mars exploration has frequently been a topic in current news and media culture. However, some participants still reported learning new information about these content goals, and expressed their ideas during the flash interview, responding to the question, "What, if anything, did you learn about human space exploration from viewing this show?" These analyses suggest that the planetarium show further confirmed thoughts about technology for space travel that youth might have already had before the planetarium show, or that it may have contributed to minor increases in understanding about these topics.

3.2 Although most of the middle school youth agreed that human space exploration was important before viewing the show, some reported an increased sense of its importance after the show, because it leads to new learning or because humans might need to live on another planet someday.

Another aim of the planetarium show was to convey why space exploration is important, particularly human space exploration. On a survey, youth were asked to rate their pre- and post-agreement with the statement, "Human space exploration is important." Youth provided agreement responses to this question using a four-point scale ranging from "strongly disagree" to "strongly agree." They were also asked to elaborate on their views of space exploration in a post-show interview question regarding what, if anything, they thought was important about space exploration.

For the statement, “Human space exploration is important,” there were no statistically significant differences between the retrospective pre- and post- responses, which could be due to initially high ratings of agreement (Figure 7). Prior to viewing the show, many youth “strongly agreed” or “agreed” that human space exploration is important (88%, of n=87). After viewing the show, youth still largely agreed that human space exploration is important (84%), with an increase in the “strongly agree” category from 36% beforehand to 45% after the show. Overall, 20% of students increased their ratings for this question from pre- to post-. After viewing the planetarium show, youth were also asked the interview question: “What, if anything, do you think is important about space exploration,” which provided insight about why youth feel that space exploration is important. Youth most often shared that space exploration is important because it can lead to new learning or discovery about the universe, technologies, or other life (39%). Just over one-quarter of youth also discussed the idea that humans may need to live on a different planet at some point (28%). Interview responses to this question (n=54) can be found in Table 3, below.

FIGURE 7. Ratings of the importance of human space exploration.

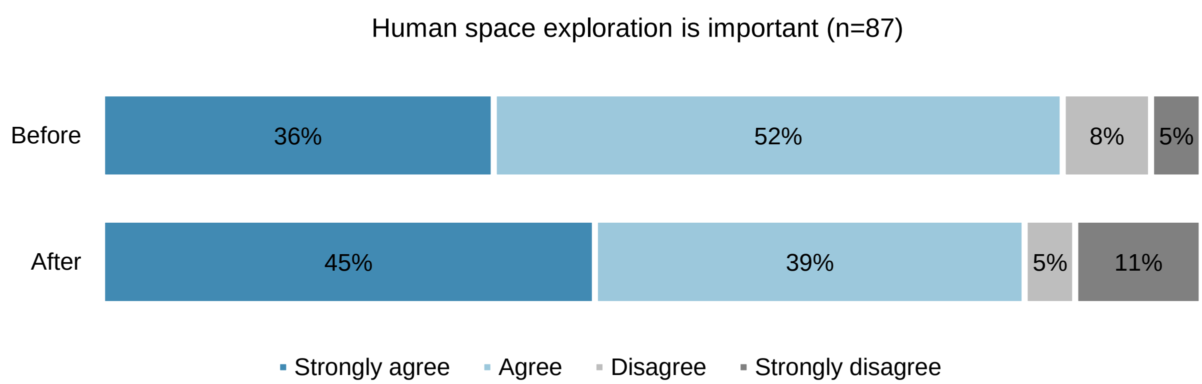


TABLE 3. Interview response categories to "What, if anything, do you think is important about space exploration?"

Code about importance	# of responses (n=54)	% of responses (n=54)	Example quotation
New learning or discovery about the universe, technologies, or other types of life	21	39%	*Finding new places and hitting check points in our research and technology.*
Humans may need to know how to live on another planet	15	28%	*There's a chance we could live on Mars.*
Space exploration can be dangerous	5	9%	*Dangers of going.*
Facts about space or space travel	3	6%	*[It is] important to wear [a] space suit because of [the] atmosphere.*
Space exploration affects life on Earth	3	6%	*Helps humans understand how to prevent asteroids from earth.*
Space exploration affects life in space	2	4%	*Gives us advice for being astronauts.*
The future	2	4%	*Plan for the future.*
I don't know	6	11%	*No idea.*
Other	6	11%	*[To] find out if there is aliens. I hope there is because I like aliens.*

Note: Responses can be coded into multiple categories

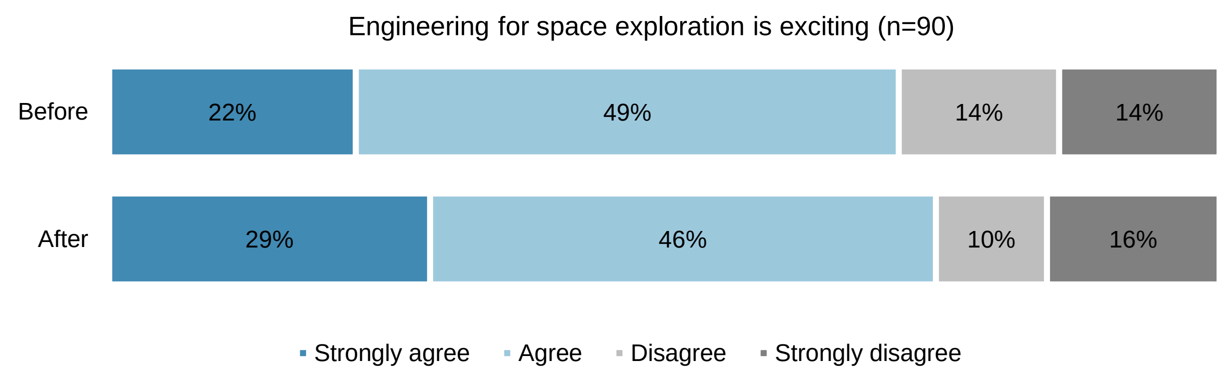
Curiously, when participants were asked to share their agreement with the statement, "Human space exploration is important," the "strongly disagree" category increased from 5% before the show to 11% after the show. The interview responses related to the importance of space exploration may shed some light on this increase, as they note that space exploration can be dangerous (9%, Table 3). Perhaps this sentiment made some participants question the importance of human space exploration.

It appears that many youth recognized the importance of space exploration prior to viewing the planetarium show. Some participants became more certain in their feelings that human space exploration is important after the show, while others may have been lead to question its importance. Youth interview responses highlight that humans can learn more about the universe through space exploration, as well as the feeling that space exploration could influence the ability of humans to live on a different planet.

3.3 Middle school youth reported coming in with high levels of excitement for engineering for space exploration but the planetarium show did not appear to have a sizable effect on their interest in activities about human space exploration. Nevertheless, middle school youth indicated small increases in interest for long-term activities about science and engineering after viewing the planetarium show.

The survey included a pre-post retrospective question that asked participants whether engineering for space exploration was exciting to them. Youth provided agreement responses to this question using a four-point scale ranging from "strongly disagree" to "strongly agree." There were no statistically significant differences between pre- and post- responses, however many of the 90 youth who responded to this question agreed that engineering for space exploration was exciting. Prior to viewing the planetarium show, 71% of youth "agreed" or "strongly agreed" that space exploration was exciting. After viewing the planetarium show, this percentage rose to 75%, with a slight increase in the "strongly agree" category (rising from 22% to 29%). Overall, 21% of students increased their ratings for this question from pre- to post-. These data are visualized in Figure 8.

FIGURE 8. Responses about excitement for engineering in space exploration.

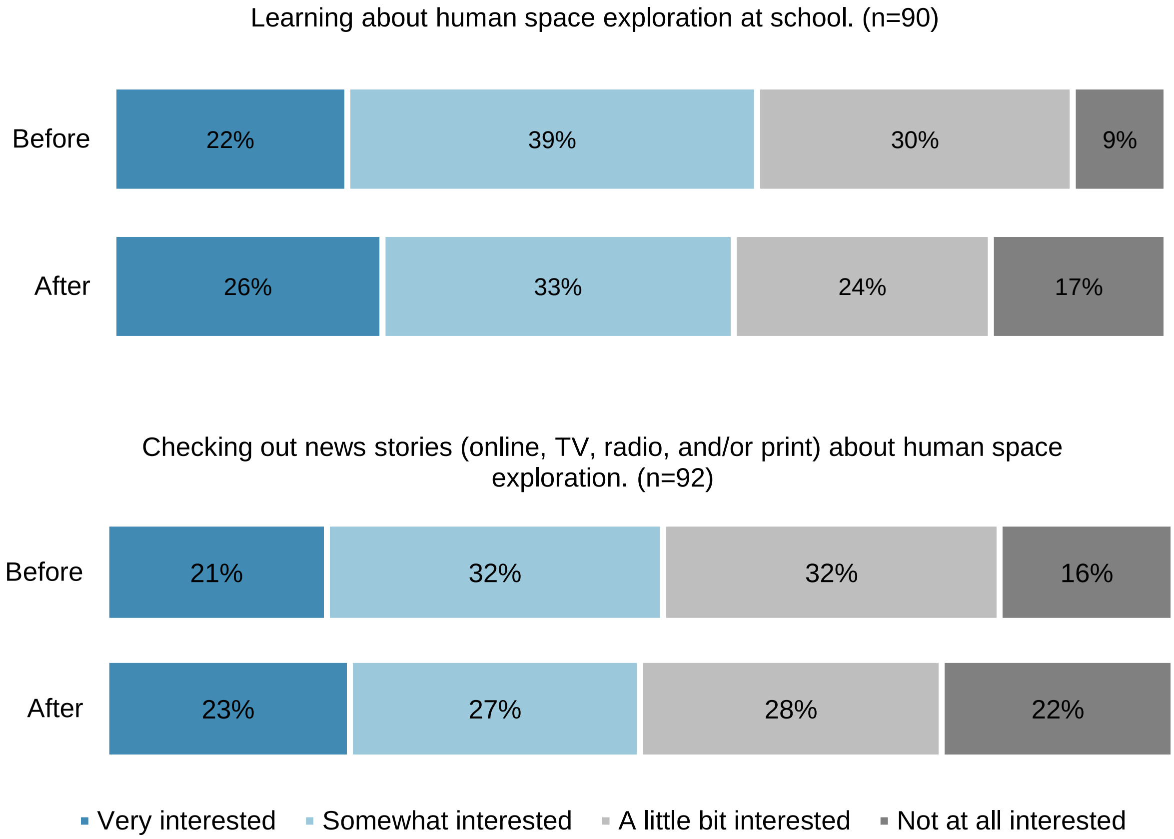


The survey captured reported change in youth interest related to future activities about space exploration, including: 1) Learning about human space exploration at school and 2) Checking out news stories about human exploration. Youth provided agreement responses to these questions using a four-point scale ranging from "not at all interested" to "very interested." None of these future activities resulted in statistically significant pre- to post- differences.

Prior to viewing the planetarium show, over half of the youth respondents shared that they were very interested or somewhat interested in learning about human space exploration at school (61% of n=90). For this activity, there was a small increase in the "very interested" category (from 22% to 26%). However, there also was an increase in "not at all interested" responses in the post- category (from 9% to 17%). Overall, 20% of students increased their ratings for this question from pre- to post-. These data are visualized in Figure 9.

When asked about their interest in checking out news stories related to human space exploration, many youth were "somewhat" or "a little bit" interested in checking out news stories (64% of n=92). Figure 9 shows that their ratings did not shift very much after viewing the planetarium show, although both ends of the scale saw minor increases: The percentage of people who reported being "very interested" increased from 21% to 23%, and "not at all interested" responses increased from 16% to 22% after seeing the planetarium show. Overall, 23% of students increased their ratings for this question from pre- to post-. Figure 9 summarizes these data.

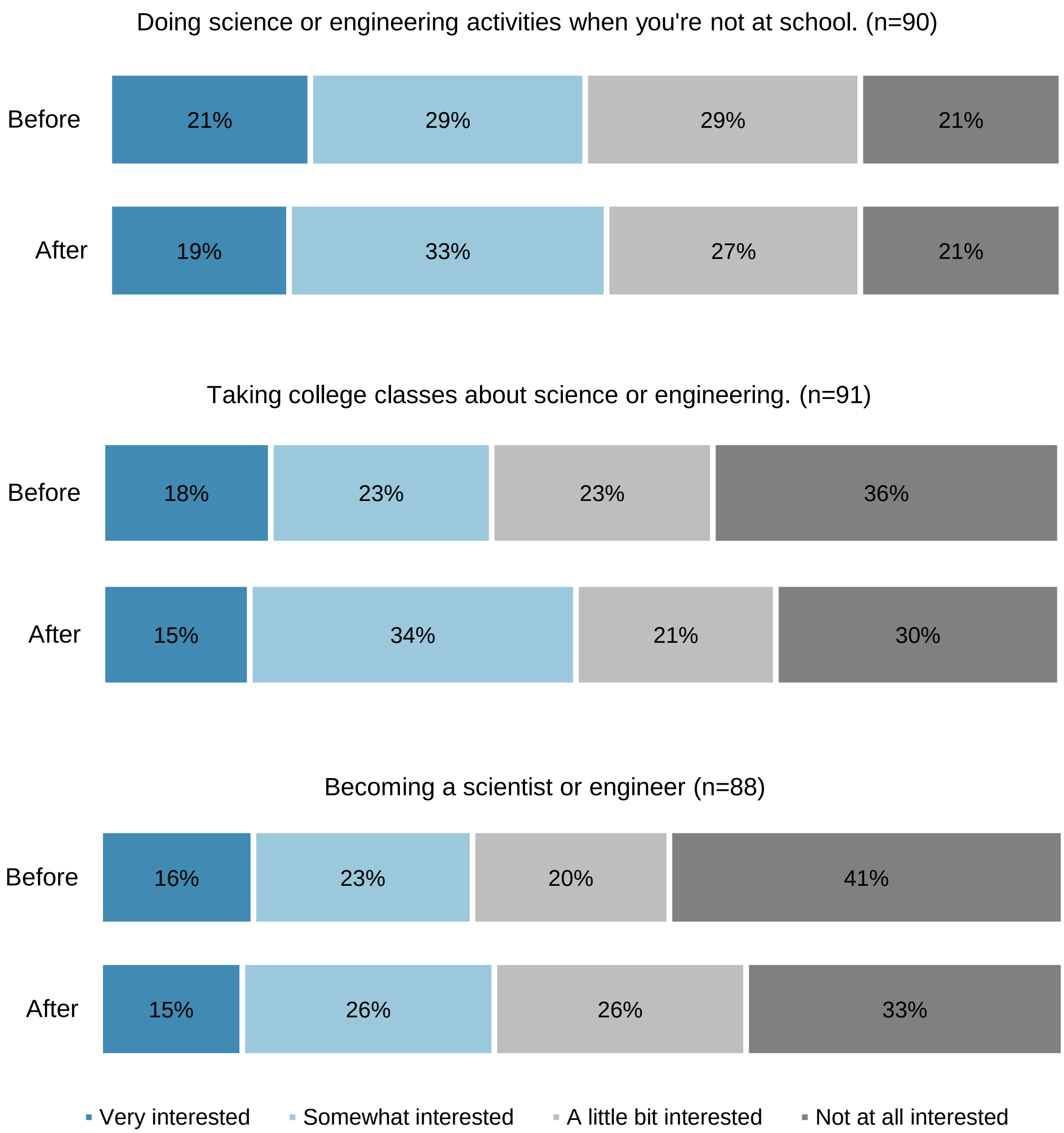
FIGURE 9. Interest in future activities about human space exploration.



The survey also captured change in youth interest related to future activities about science and engineering. These included interest in: 1) Doing science and engineering activities when you're not in school, 2) Taking college classes about science or engineering, and 3) Becoming a scientist or engineer. In comparing the retrospective pre- and post- survey responses, youth provided agreement responses to these questions using a four-point scale ranging from "not at all interested" to "very interested." Changes for these follow up activities were minimal, and as such, there were no statistically significant differences between pre- and post- responses for any of these activities. Figure 10 shows that prior to viewing the planetarium show, half of the respondents were "very" or "somewhat" interested in doing science or engineering activities when not in school (50% of n=90). The same interest categories increased slightly after viewing the planetarium show (52%). Overall, 20% of students increased their ratings for this question from pre- to post-.

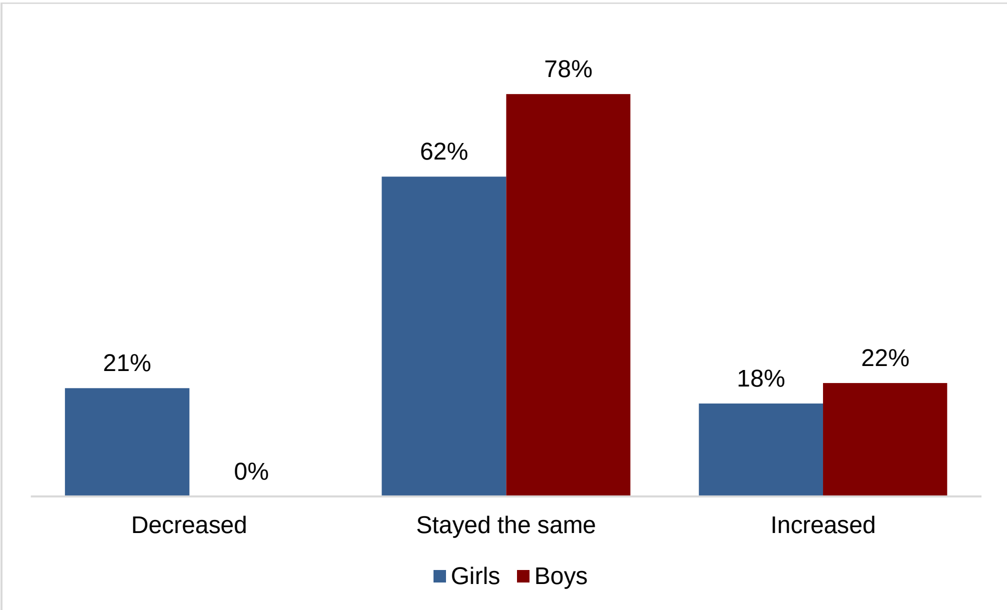
Prior to viewing the planetarium show, 41% of 91 youth reported being "very" or "somewhat" interested in taking college classes about science or engineering (Figure 10). After viewing the planetarium show, almost half of youth (49%) reported interest levels in these highest categories. Additionally, fewer youth reported being "not at all interested" (30%) than before viewing the show (36%). Overall, 27% of students increased their ratings for this question from pre- to post-. This suggests that the planetarium show encouraged viewers to consider taking college classes about science or engineering, when they may not have previously felt this way. However, this was not true for all respondents; the percentage of youth who reported being "very interested" decreased slightly from 18% before the show to 15% after the show. Overall, 18% of students decreased their ratings for this question from pre- to post-.

FIGURE 10. Interest in future activities about science and engineering.



When asked about their level of interest in becoming a scientist or engineer, the greatest change between retrospective pre- and post- responses was a decrease in the "not at all interested" category after viewing the planetarium show (shrinking from 41% to 33%, n=88). There was also a slight increase across the highest two categories, "very" and "somewhat" interested (from 39% to 41%). Overall, 17% of students increased their ratings for this question from pre- to post-. Figure 11 visualizes these data. Results from a two-way ANOVA analysis indicated a statistically significant main effect of gender (F=4.60, p=0.036). Boys of all ages reported more career interest than girls, with the mean difference score for boys being more than one-half (0.529) standard deviation higher than that of girls (mean boys=.42, mean girls=-0.079, SD across groups=.951). Figure 11 below shows the percentage of boys and girls whose scores decreased (negative change score), stayed the same, or increased (positive change score). No significant main effect was found for age.

FIGURE 11. Summary of change scores by gender for the item "Becoming a Scientist or Engineer." (n=39 for girls, n=32 for boys)



Many youth agreed that engineering for space exploration is exciting, but this sentiment did not translate into changes across future activities about this topic. In comparing the retrospective pre- and post- responses to the questions about future activities, there were no statistically significant differences for any of the specified activities. There were minimal changes between levels of agreement for activities related to human space exploration. It is possible that the retrospective question about interest in checking out news stories about human space exploration could have been reframed to be more relevant to middle school youth. There were also minimal changes between levels of agreement for future activities related to science and engineering. However, 27% of youth increased their interest in taking college classes about science and engineering (the greatest overall increase across planetarium show-related questions). On the other hand, interest in becoming a scientist or engineer stayed the same or increased for some boys and girls, while 21% of girls reported a decrease in interest. These results suggest that aspects of the planetarium show did not engage girls in the same way as boys.

IV. DESIGN CHALLENGE FINDINGS

This section shares data related to how participation in the engineering design challenge impacted the attitudes of middle school youth toward space exploration, and the extent to which these youth participated in and recognized the engineering design process. Data were collected through observations at the activity, a retrospective pre-post survey, and a brief interview. Observations focused on participants' behaviors related to the engineering design process, such as whether they built and tested a design, and if so, how many times they tested iterated designs. The survey asked respondents to 1) indicate their interest in follow-up activities about space exploration or science and engineering, and 2) rate their level of agreement with statements about human space exploration. Participants also responded to two interview questions after the planetarium show about 1) the engineering design process and 2) what they thought was exciting about space exploration.

Findings in this section will address questions 4.1 through 4.4, and the relevant findings are listed below each question:

4.1 To what extent does experiencing the activity increase participants' opinions that human space exploration is important?
There were small changes in participant's perception that human space exploration is important, and the activity helped them understand the challenges involved in human space exploration.

4.2 To what extent does experiencing the activity increase participants' interest in future activities and careers in engineering and science?

- **4.2.1** ***After doing the activity, participants reported significantly higher interest in learning about human space exploration at school, taking college classes in science or engineering, and becoming a scientist or engineer.***
- **4.2.2** ***Youth reported that doing the activity made them: want to learn more about human missions to Mars, more likely to think about becoming an engineer, and excited to think about solutions to engineering challenges of a Mars mission. Boys of all ages more strongly agreed that they were excited to think about solutions to engineering challenges.***
- **4.2.3** ***Participants generally agreed that human space exploration is exciting. When asked what about human space exploration was exciting to them, participants most often said either "exploring" or "learning new things."***

4.3 To what extent do participants engage in the engineering design process?
About two-thirds of participants fully engaged in the engineering design process, defined as Ask/Imagine/Plan, Create/Build, Test, and Improve.

4.4 To what extent do participants identify that they are engaged in an activity that is like what an engineer does?
73% of participants strongly agreed or agreed that they did something like what an engineer does. When asked what they did that was like what engineers do, almost all the middle school youth said something about building their Mars habitat.

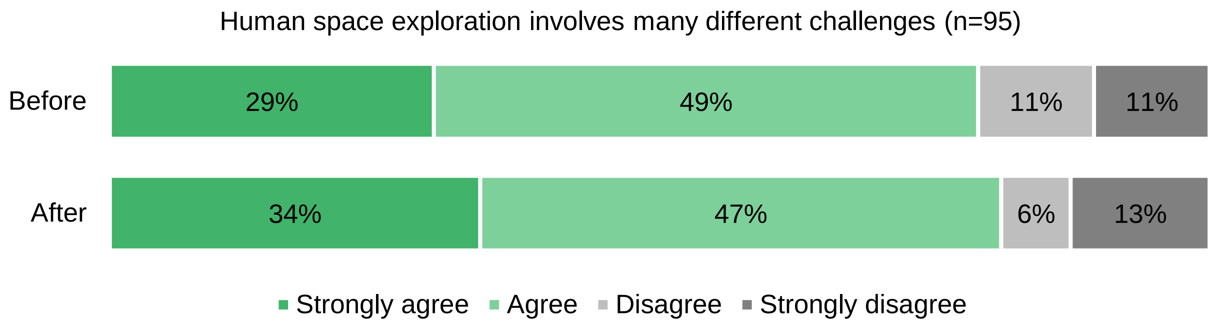
4.1 There were small changes in participant's perception that human space exploration is important, and the activity helped them understand the challenges involved in human space exploration.

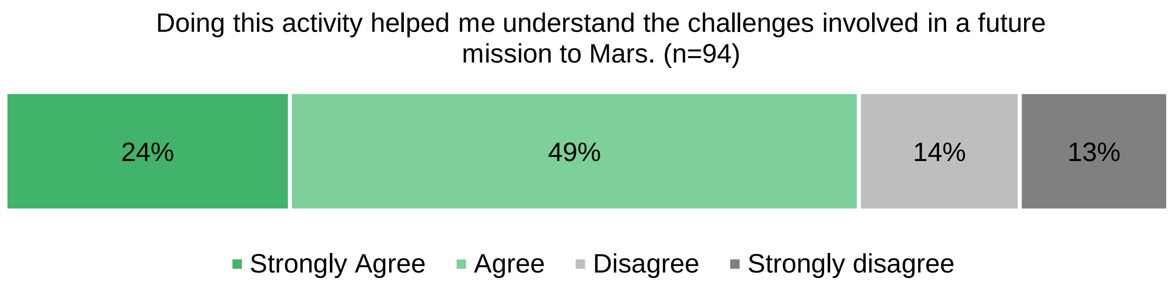
Activity participants were asked to rate their level of agreement with two statements related to the importance of human space exploration: 1) "Human space exploration is important" and 2) "Human space exploration involves many different engineering challenges." For these two statements, participants retrospectively rated their level of agreement on a 4-point scale from "Strongly disagree" to "Strongly agree" before doing the activity, as well as their agreement afterward.

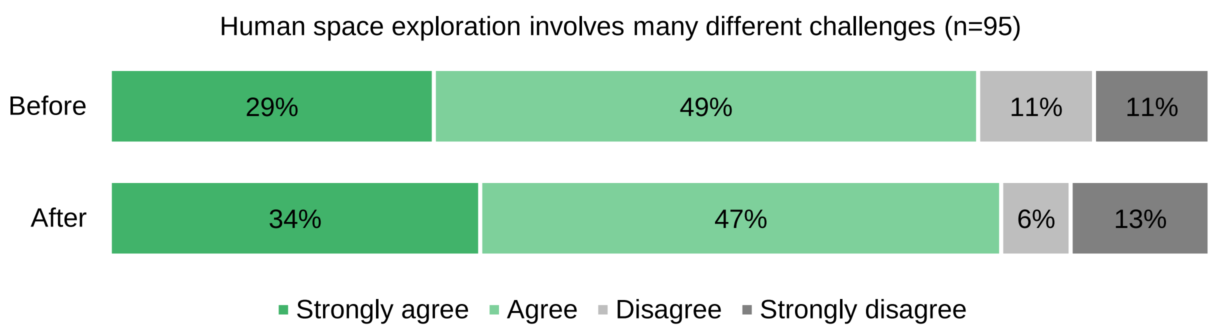
Participants tended to agree that the activity helped them understand the challenges involved in human space exploration. As shown in Figure 12 below, from before to after the activity, the percentage of participants strongly agreeing that human space exploration involves many different engineering challenges rose from 29% to 34% (n=95). When looking at the combined percentages for "strongly agree" and "agree," the percentage rose slightly from 78% before the activity to 81% after. Overall, 20% of students increased their ratings for this question from pre- to post-.

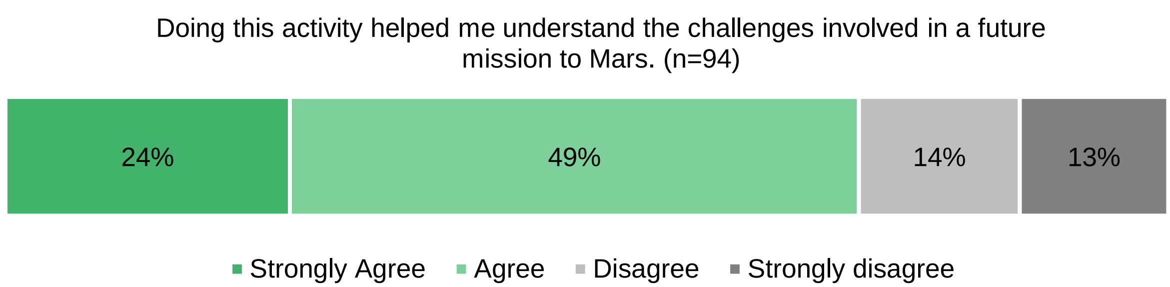
Despite the modest changes between retrospective pre- and post- responses, when looking at their responses to the direct post-only question, participants generally agreed that participating in the activity helped them understand the challenges that could be involved in a mission to Mars. As shown in Figure 12 below, 73% of participants either strongly agreed or agreed that doing the activity helped them understand some of these challenges (n=94). None of these changes were statistically significant.

FIGURE 12. Responses related to the activity's connection to engineering challenges in human space exploration.



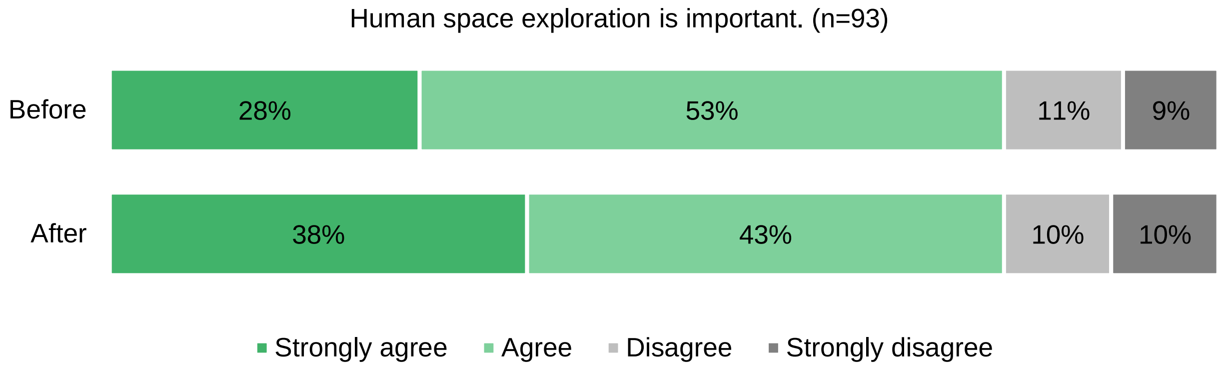


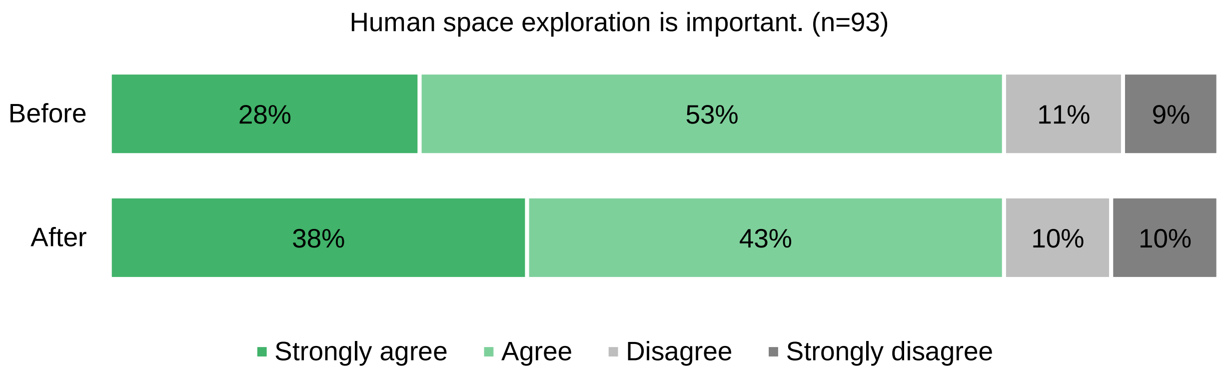




There were also small changes in participants' perception of the importance of human space exploration, though these changes were also not statistically significant. From before to after the activity, the percentage of participants who strongly agreed that human space exploration is important rose 10%, from 28% to 38% (n=93). When looking at the combined percentage of participants who agreed and strongly agreed, there was little change from pre- to post-. The combined percentage of “strongly agree” and “agree” stayed at 81% before and after the activity. Overall, 19% of students increased their ratings on this rating from pre- to post-.

FIGURE 13. Pre- and post- responses related to the importance of human space exploration.





While the changes are somewhat modest, it is encouraging that all of these data points show growth in understanding of, and support for, human space exploration. This is true both of the metacognitive question of whether or not the youth felt they had learned from the show, as well as the retrospective questions asking youth to rate their understanding and support before and after the show. It is also notable that youth’s baseline levels of support and understanding were quite high across all three questions.

4.2.1 After doing the activity, participants reported significantly higher interest in learning about human space exploration at school, taking college classes in science or engineering, and becoming a scientist or engineer.

Activity participants were asked to rate their level of interest on a 4-point scale from “Not at all interested” to “Very interested,” before and after doing the design challenge, in five activities related to human space exploration, science, or engineering:

1. Checking out news stories about human space exploration,

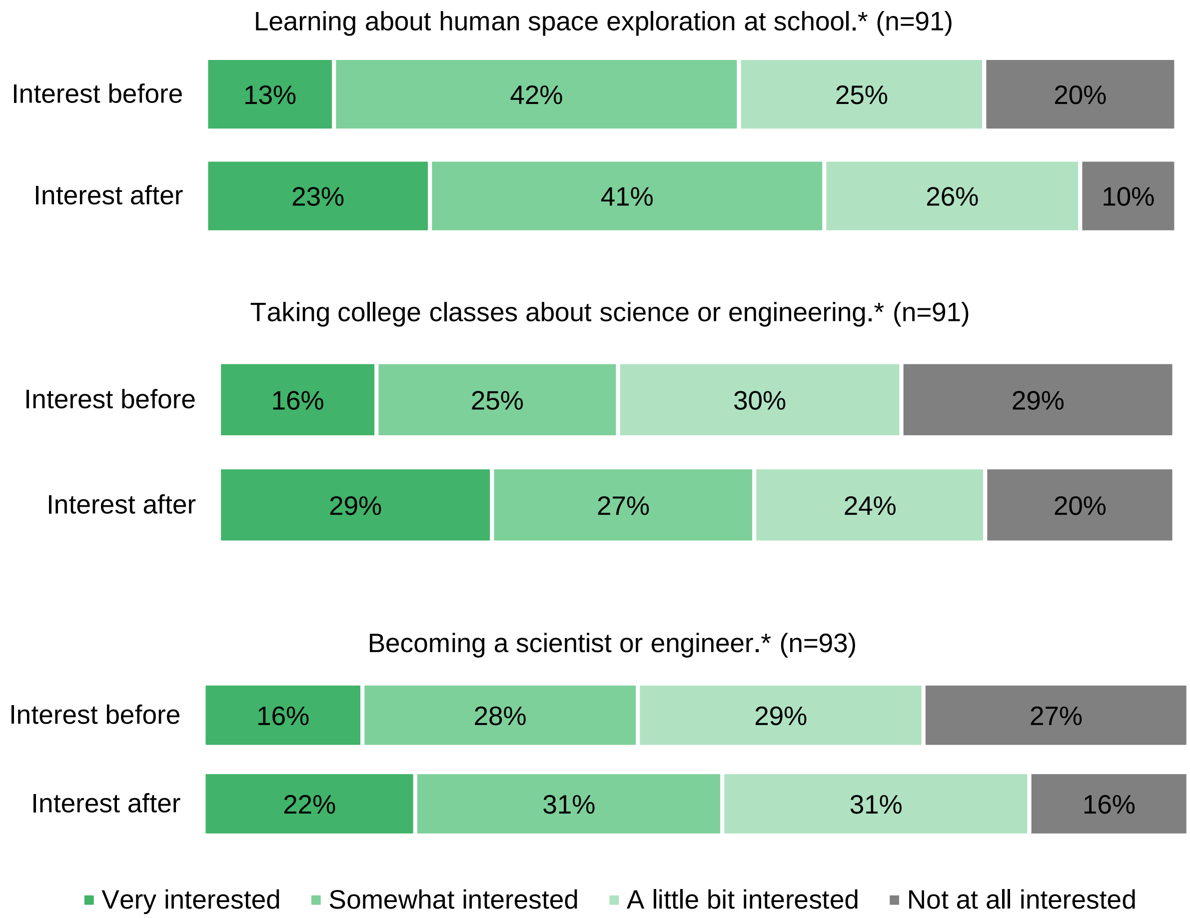
2. Learning about human space exploration at school,
3. Learning about human space exploration outside of school,
4. Taking college classes about science or engineering, and
5. Becoming a scientist or engineer.

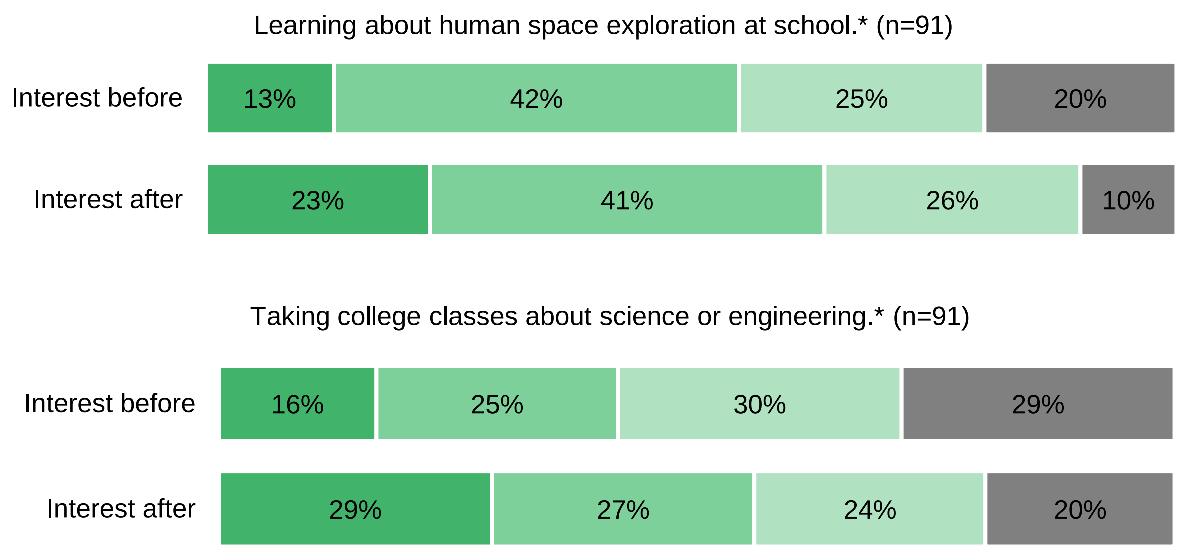
From before the activity to after, Wilcoxon signed-rank tests showed that participants reported significantly higher interest in two of the activities, with a medium effect size: learning more about human space exploration at school ($Z = -3.276$, $p = .001$, $n=91$, $r=-0.343$) and taking college classes in science or engineering ($Z = -3.363$, $p = .001$, $n=91$, $r=-0.353$).

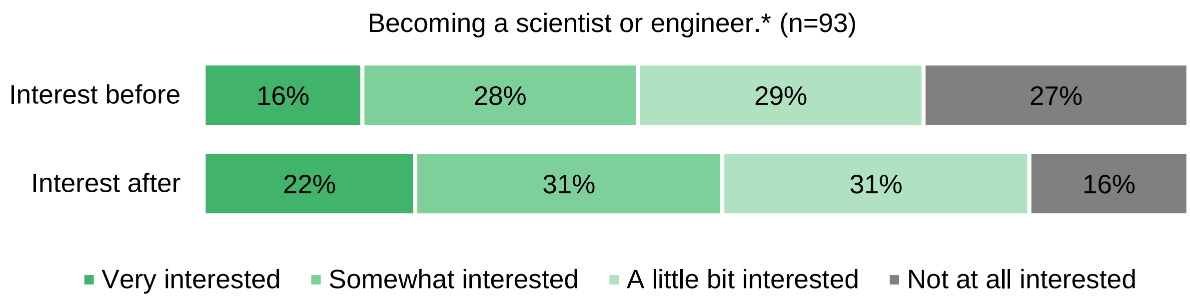
The percentage of participants reporting that they were "very interested" in learning about human space exploration at school rose from 13% to 23% (n=91), and 30% of participants increased their ratings from pre- to post-. In addition, the percentage of participants reporting that they were "very interested" in taking college classes about science or engineering rose from 16% to 29% (n=91). In this case, 33% of participants increased their ratings from pre- to post-.

Respondents reported statistically higher interest, with a small effect size, for a third activity, becoming a scientist or engineer ($Z = -2.453$, $p = 0.014$, $n=93$, $r=-0.254$). The percentage of participants reporting that they were "very interested" in becoming a scientist or engineer rose from 16% to 22%. Overall, 27% of participants increased their ratings from pre- to post- on this item. The pre- and post- response distributions for all three items are shown in Figure 14 below.

FIGURE 14. Activities for which youth reported significant increases in interest after doing the design challenge activity.



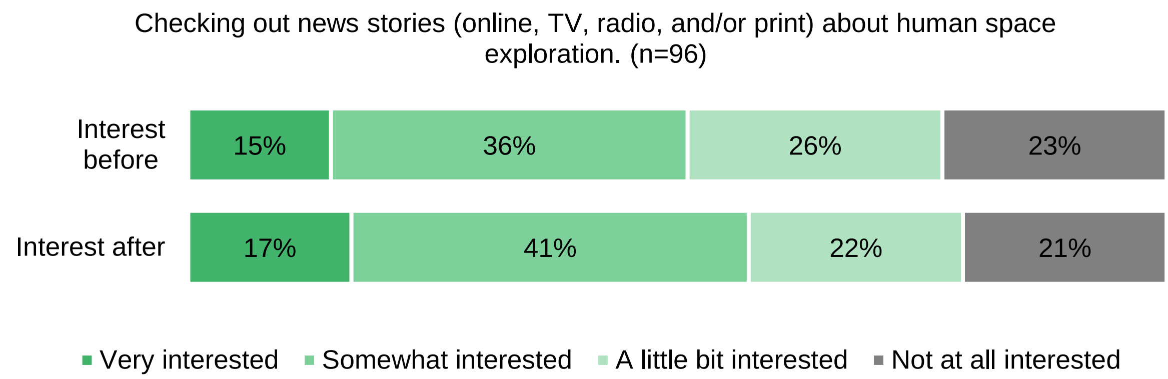


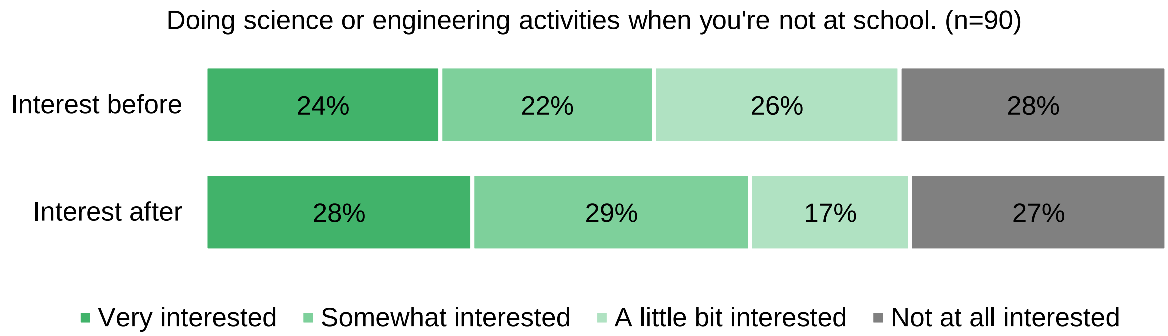


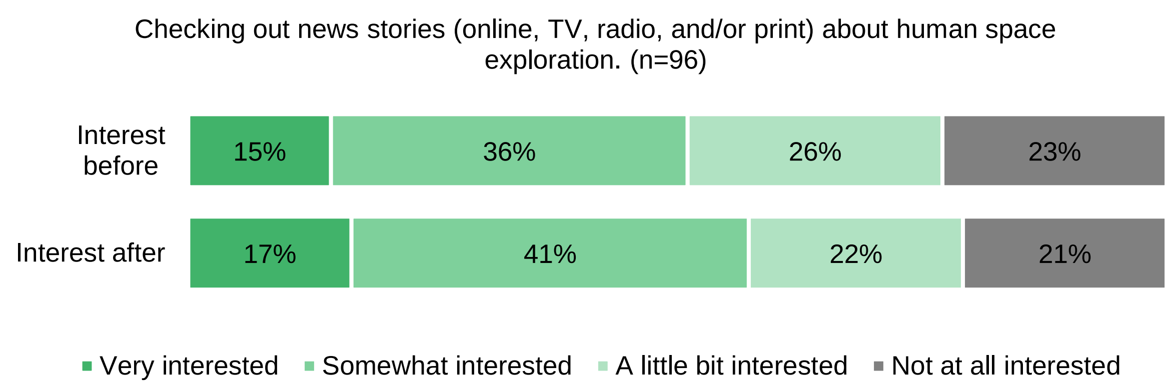
Participant responses also indicated small increases in interest in the other two activities, "checking out news stories" and "learning about human space exploration outside of school" but neither increase was statistically significant. These changes tended to be more in the percentage of participants who selected "somewhat interested." The percentage of participants reporting that they were "very" or "somewhat" interested in checking out news stories about human space exploration rose from 51% to 58%, and 26% increased their ratings from pre- to post-. The percentage of participants reporting that they were "very" or "somewhat" interested in doing science or engineering activities outside of school rose from 46% to 57%, and 21% of participants increased their response from pre- to post-.

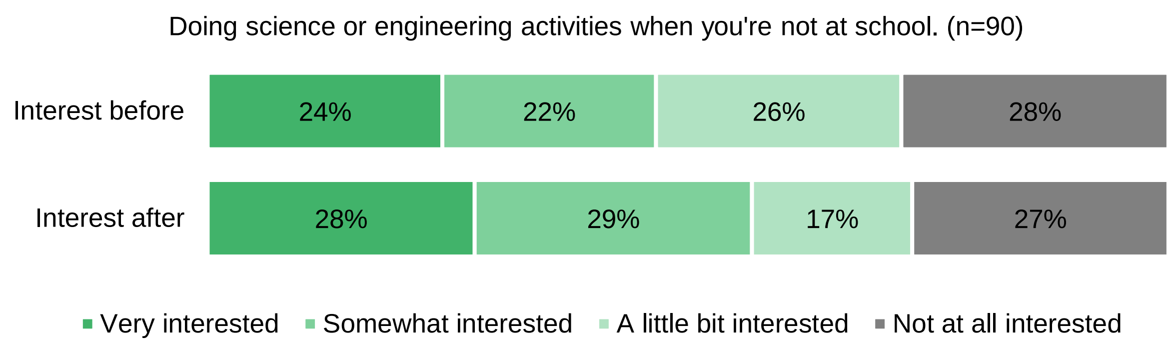
These pre- and post- response distributions for these two items are shown in Figure 15 below.

FIGURE 15. Activities for which youth did not report significantly increased interest after doing the design challenge activity.







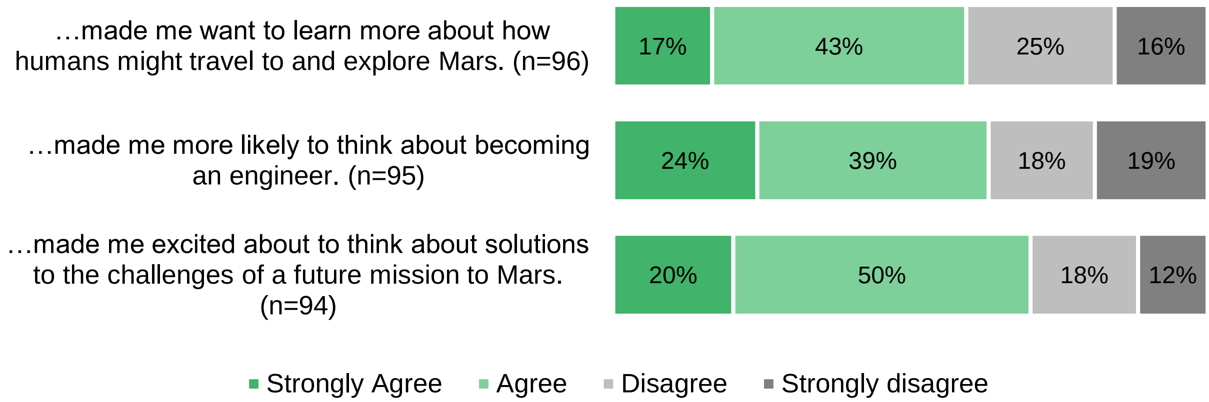


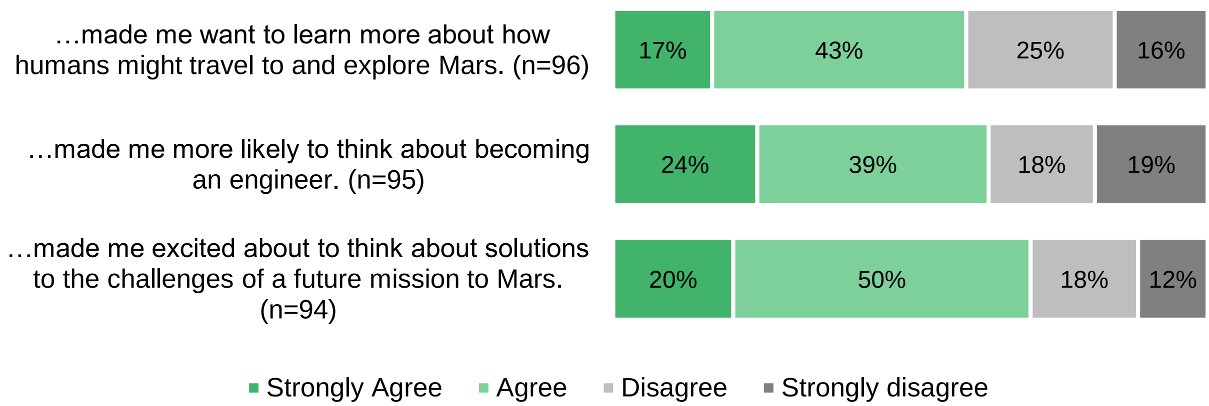
4.2.2 Youth reported that doing the activity made them: want to learn more about human mission to Mars, more likely to think about becoming an engineer, and excited to think about solutions to engineering challenges of a Mars mission. Boys of all ages more strongly agreed that they were excited to think about solutions to engineering challenges.

Youth also answered three direct questions about whether doing the activity made them more interested in, or excited about, activities related to human space exploration. These items were not rated on a retrospective pre-post basis. Participants rated them on a 4-point scale from "Strongly disagree" to "Strongly agree." As shown in Figure 16, participants tended to agree that doing the activity made them want to learn more, made them excited to think about solutions, and made them more likely to think about becoming engineers.

For all three statements, at least half of youth reported that they "strongly agreed" or "agreed." 50% agreed that they wanted to learn more about how humans might travel to Mars (n=96), 63% that they would be more likely to think about becoming an engineer (n=95), and 70% agreed that they would be more excited to think about solutions to the engineering challenges involved with a Mars mission (n=94). Almost a quarter (24%) of students strongly agreed that doing the activity made them more likely to think about becoming an engineer (n=95).

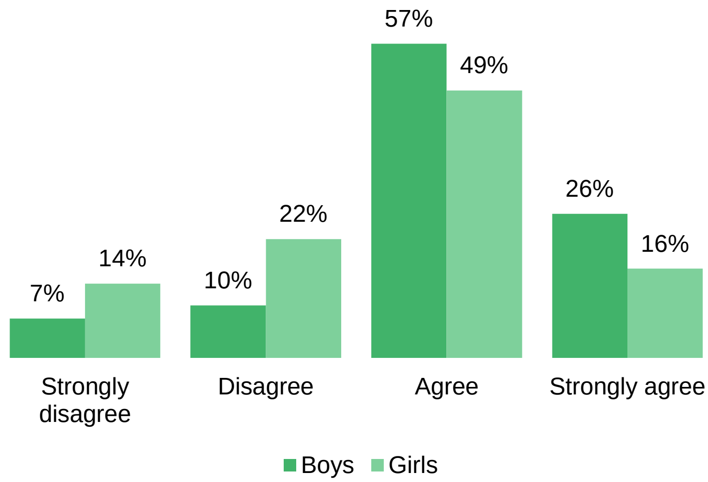
FIGURE 16. Youth responses to post-only questions with “Doing this activity…”

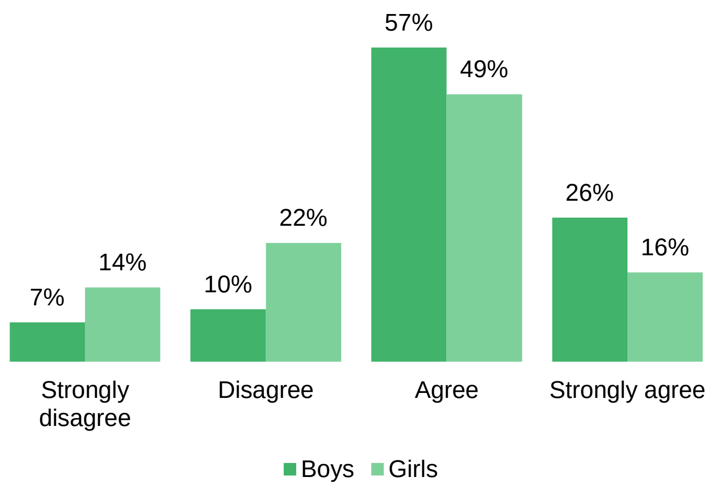




The item related to thinking about solutions to the challenges involved in a future Mars mission was one where further analysis showed an interaction effect. In this case, there was an interaction effect with gender. Results from a two-way ANOVA analysis indicated a statistically significant main effect of gender ($F=4.10$, $p=0.046$, $n=94$). Boys (of all ages) rated their agreement with this statement more highly than girls did, with the mean score for boys being roughly one-half of a standard deviation higher than that of girls (3.07 and 2.68 respectively, sd across groups=.853). No significant main effect was found for age. Figure 17 below shows how boys and girls rated their agreement with the statement.

FIGURE 17. Boys' and Girls' Agreement with the Statement "Doing this activity made me excited to think about solutions to engineering challenges of a Mars mission." (n=47 for boys, n=35 for girls)



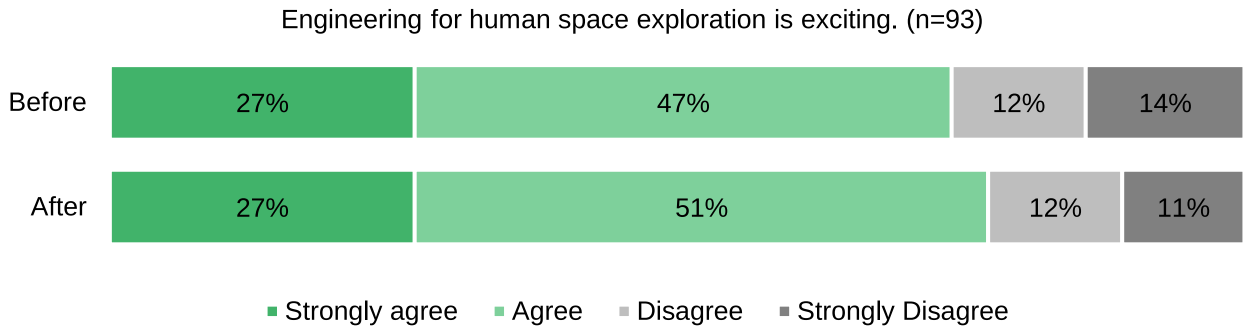


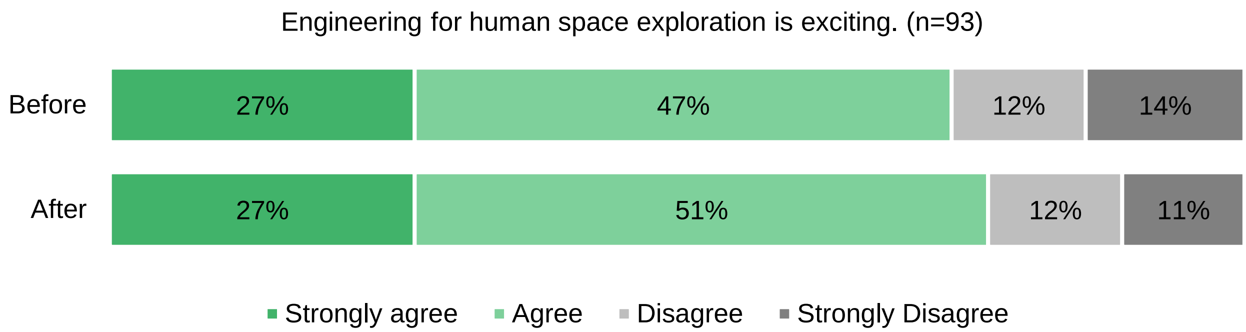
"Thinking about solutions" to engineering challenges is something that engineers do in their work, and this gender effect could be related to the broader cultural phenomenon that more men than women study engineering and enter engineering careers. While the Museum provides programming that engages all youths in engineering activities in order to help close this gap, it still exists.

4.2.3 Participants generally agreed that human space exploration is exciting. When asked what about human space exploration was exciting to them, participants most often said either "exploring" or "learning new things."

Participants retrospectively rated their agreement on a 4-point scale from "Not at all interested" to "Very interested" before and after doing the activity with the interest-related statement: "Human space exploration is exciting." While youth tended to agree with this statement, suggesting that they believe human space exploration is exciting, the change from pre- to post- was not statistically significant. The combined percentage of respondents selecting “strongly agree” or “agree” rose from 74% to 78%. In addition, 22% of participants’ scores increased from pre- to post-. Responses to this item are shown in Figure 18 below.

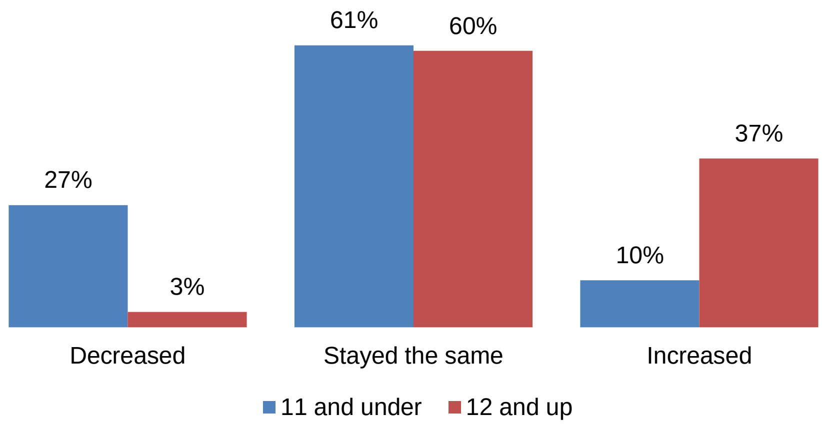
FIGURE 18. Retrospective pre- and post- responses about perceptions of human space exploration as exciting.

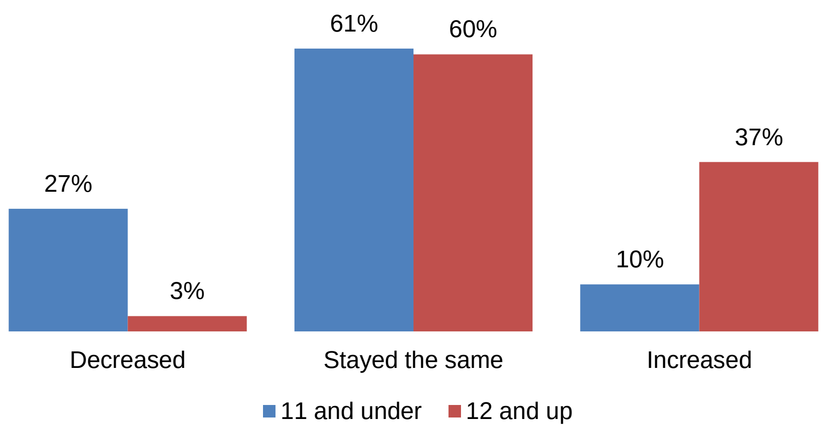



Engineering for human space exploration is exciting. (n=93)
Before
27%
47%
12%
14%
After
27%
51%
12%
11%
Strongly agree
Agree
Disagree
Strongly Disagree

Results from a two-way ANOVA analysis indicate a statistically significant main effect of age (F=10.86, p=0.002, n=93). When looking at difference scores (the difference between each participant’s pre- and post- score), children 12 and older consistently rated space exploration as more exciting than those 11 and younger, with the mean difference score for older children more than one half scale point higher than that of younger children. No significant main effect was found for gender. Figure 19 below shows the percentage of older and younger children whose scores decreased (negative change score), stayed the same, or increased (positive change score).

FIGURE 19. Summary of Change Scores by Age for the Item "Human Space Exploration is Exciting." (n=49 for Age <=11, n=30 for Age >=12)





The effect may be because older children may have had more exposure to ideas and information about human space exploration, or more opportunities to learn about it in school. They also may be reaching an age when they are becoming more independent, and so things like "exploring new environments" or "discovering new things" begin to pique their interest more (as shown in the open-ended data below).

In the flash interviews after the activity, a subset of youth (n=41) were asked what, if anything, they felt was exciting about human space exploration. Youth mentioned several things they felt were exciting, and the most common categories were 1) learning or discovering new things (18 respondents), and 2) the experience of exploring or getting to space (15 respondents). These types of responses were more common than responses related to engineering or building. However, nine respondents did mention that they thought that the technology or engineering involved was an exciting thing about human space exploration. The codes for the flash interview questions are shown below in Table 4.

TABLE 4. Responses to design challenge flash interview question, "What, if anything, do you feel is exciting about human space exploration?"

Code about excitement	# of responses (N=40)	% of responses (N=40)	Example quotation
Learning, finding, or discovering new things	18	45%	Exciting that you get to learn new things about space and planets.
Exploring new environments or going to space	15	38%	Explore new worlds like Mars.
Building/engineering or the technology involved	9	23%	Making the spaceship.
I don't know	2	5%	I don't know.
Nothing	1	3%	To me, nothing.
Other	2	5%	One thing is that we could experience other things.

Note: Responses can be coded into multiple categories

Across these findings about interest, we see that youth reported excitement and interest both in human space exploration and in future activities related to the topic of engineering. The data ask about different aspects of this topic, ranging from open-ended ways of describing youth's excitement to Likert-scale factors that assess the extent of interest to retrospective pre- and post-questions that provide comparative levels of change. As with other areas in this report, youth reported relatively high levels of interest prior to their engagement in the design challenge activity, which means there was limited room for additional growth. However, the youth nonetheless reported positive changes, several of which were statistically significant.

4.3 About two-thirds of participants fully engaged in the engineering design process, defined as Ask/Imagine/Plan, Create/Build, Test, and Improve.

Participants at the Design Challenge activity got the opportunity to plan, build, test, and improve a "hab" structure for Mars. While observing the activity, researchers kept track of whether the focus subject engaged in the four main steps of the engineering design process: Ask/Imagine/Plan, Create/Build, Test, and Improve. Researchers looked for several different behaviors that fit into those four overall categories (see the observation form in Appendix A).

When looking at what portion of youth were observed taking part in at least one activity in each engineering design process category, the percentage of youth engaging in the engineering design process was about two-thirds, as seen in Figure 19. The percentages below are inclusive, i.e. all youth who participated in the "Improve" step also took part in the previous steps.

FIGURE 19. Percent of youth participating in the steps of the engineering design process (n=62).

All observed youth were observed doing activities related to the Ask/Imagine/Plan step, often listening to the instructions, exploring the available materials or discussing a goal. For example, the focus child in Group 62 was observed discussing the activity with his group, saying, “I want to make it better. My goal is to make it wide.” Later, while building, he said, “I want to get it to stand up.”

Though a few youth abandoned the activity before building, 96% did activities in the Create/Build category. Youth often discussed their ideas, the materials, or the building process while creating their designs. For example, the focus child in group 24 said, while building, “Why is this so wobbly?” An adult with her said, “You don't like it?” She then confirmed, “It's too wobbly.” Youth had to work through similar challenges with their designs as part of the activity.

In order to test, youth brought their design to a designated, staffed testing station. Sometimes they waited in line to test. Participants sometimes talked about their designs during testing or described the results. For example, the focus child in Group 26 predicted the results as he watched the testing, asking, “Did it fully drop?” and commenting, “I'm going to make it blast off! My robot’s going to fold.” Design challenge facilitators also kept a record board for any designs that recorded the highest height measurement within a particular width zone. If a youth’s design got the record, they could name it and have it displayed on the record board. Participants sometimes talked about the record board and wanted to beat the day’s record. For example, two children in Group 28 discussed the record as they went to test, with one saying, “We have to beat that.” Her partner replied, “The tallest was 22 cm.”

After testing, participants sometimes got specific ideas about how to improve their design. For example, two youths in Group 31 tested and got a better idea of how the testing station worked.

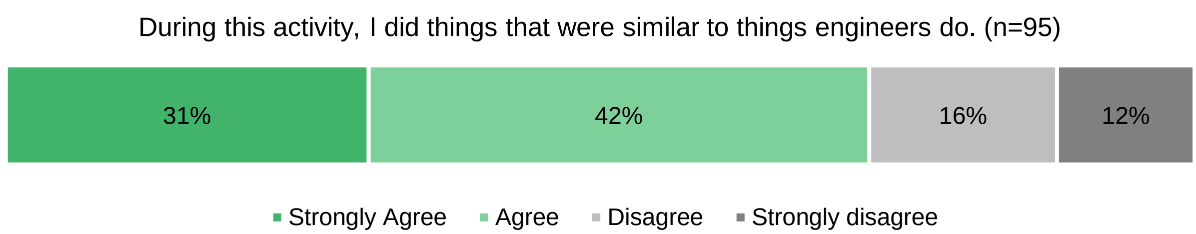
Afterward, one said, "Some of these [rubber connectors] got stuck." They proceeded to rework their whole design, discussing together what they should do. One youth said, referring to the materials, "We're not adding this." Her partner replied, "It has to be taller." The first child reminded her, "One's going to be on the bottom when they put it up and then put it down."

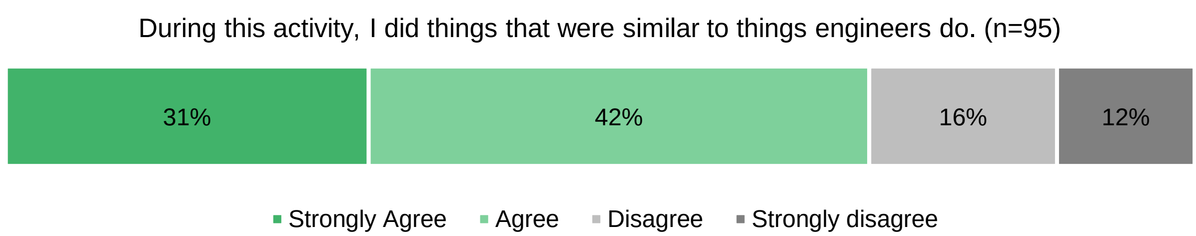
Other common observations included youths working together in teams, which 28 groups did (45% of the total), and running into usability issues, which occurred for 13 groups (21% of the total). Youth were encouraged by the adults with them to work in teams, and the design challenge staff also suggested that activity participants work in teams, especially during busy times. The most common usability issue was youth having difficulty removing the rubber connectors from the rods on their designs. Following this data collection, the design was adjusted to include a more robust rubber material.

4.4 73% of participants strongly agreed or agreed that they did something like what an engineer did. When asked what they did that was like what engineers do, almost all the middle school youth said something about building their Mars habitat.

The majority of youth surveyed said that they did indeed do something at the activity that was similar to what an engineer does. They answered this question on a 4-point agreement scale, from "Strongly disagree" to "Strongly agree." In the surveys, 73% of youth strongly agreed or agreed with this statement, as seen in Figure 20 below (n=95).

FIGURE 20. Level of agreement about doing something that was like what an engineer does.





A subset of participants (n=41) were asked the interview question, "What, if anything, did you do in this activity that was like what an engineer does?" Only one respondent said they did not know, and 30 of the 41 respondents (73%) specified creating or building. The coded responses are shown in Table 5 below, in order of the engineering design process steps.

TABLE 5. Coded responses to the question, "What, if anything, did you do in this activity that was like what an engineer does?" (n=41)

Code	# of responses (N=41)	# of responses (N=41)	Example quotation
Ask/Imagine/Plan (includes thinking, brainstorming, unspecified collaborating)	7	17%	Work as a team, share ideas.
Create (building)	30	75%	Building the spaceship and making it tall enough.
Test (include unspecified mentions of math or measurement)	4	10%	Build - test the thing we built.
Improve (include general mentions of failure)	6	15%	At first you have to fail to succeed. Can't just have one project.
Don't know	1	2%	I just forgot.

Note: Responses can be coded into multiple categories.

These data about youth participation in, and metacognition about, the engineering design process are encouraging, showing that all youth engaged in at least one stage of the process, and more than 90% participated in three or more stages of the process. Although there is a large difference in the scope and expertise required for this activity compared to the engineering of a hab structure that would actually be sent to Mars, many aspects of the basic engineering process are similar. The high rates of participation in the process shown in this data demonstrate success in developing a museum activity that requires only a short introduction and then gives visitors the potentially empowering experience of actually practicing skills that engineers use. It is further encouraging to see that nearly three-quarters of youth recognized the similarities between what they were doing and what engineers do. This metacognitive recognition could be an important step towards developing an identity as someone who is able to do engineering. Paired with the positive interest data from the previous sections, these data could be valuable building blocks towards sustained involvement in engineering.

V. DISCUSSION

Whereas the previous section presented findings for the planetarium show and design challenge for each evaluation question, this section looks across the products to consider additional context and meaning for project-level outcomes. It is organized around four main themes: learning, the importance of space exploration, interest in future behavior, and participation in the engineering design process.

Learning: Content learning was an explicit project goal for the planetarium show. Survey data show evidence supporting this goal, including a statistically significant increase in participants' agreement that technology for space travel is changing to support an exploration to Mars.[2] Participants also reported slight, but statistically insignificant increases in knowledge about work currently happening for an exploration to Mars.[3] It may be that the content about these topics was not as clear to students, or that students already knew about these topics. Across these items, the middle school youth came in with high levels of prior knowledge. This high knowledge may have led to a ceiling effect in which there was little room in the scale for participants to report improvement. Despite high levels of prior knowledge, almost all respondents indicated in the interview that they learned from the planetarium show. Thus, while not every participant learned each key message that the survey explored, they did report that the show had been educational overall. Because the design challenge was about engaging in the design process more than learning about it, there was not an explicit content learning goal for this deliverable. However, there was some evidence of learning from this activity, as well. Design challenge participants reported on the survey that the activity helped them understand the challenges involved in a future mission to Mars.[4]

The importance of space exploration: Both the planetarium show and design challenge activity sought to raise participants' sense that space exploration—with a focus on human space exploration—is important. The quantitative, retrospective pre-post-surveys asked the same question of planetarium and design challenge participants, and generated similar results. Overall, respondents tended to "agree" or "strongly agree" that human space exploration was important both before and after the learning experiences.[5] As with the learning data, the fact that a significant increase was not seen after the educational experiences may be because high pre-ratings led to a ceiling effect whereby there was little room for participants to report an increase. It may also indicate that participants overestimated their pre-experience ratings. Curiously, in these data, there were increases in the percentage of people who rated these statements at both

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[2] The percentage of respondents who agreed or strongly agreed that technology for space travel is changing to support an exploration to Mars rose from 80% to 82%, with the percentage of strong agreement rising from 27% to 38% (n=89). Wilcoxon signed-rank test: $Z=-2.01$, $p=0.04$, $n=89$, $r=-0.21$

[3] The percentage of respondents who agreed or strongly agreed that work is currently happening for an exploration to Mars rose from 81% to 84%, with the percent of strong agreement rising from 28% to 36% (n=89).

[4] 73% of respondents agreed or strongly agreed that doing the activity helped them understand the challenges involved in a future mission to Mars, n=94

[5] For the planetarium survey, the percentage of people who agreed or strongly agreed that human space exploration is important was 88% before the show and 84% afterwards (n=87). For the design challenge survey, the percentage of people who agreed or strongly agreed that human space exploration is important was 81% before the activity and 80% afterwards (n=87).

ends of the scale ("strongly agree" and "strongly disagree") after their experience. [6] This pattern of polarization may be because both activities made people feel more strongly about their opinion, whether negative or positive, indicating that the programming was helping youth form a clear stance about human space exploration such that they felt more confident in their opinions about it.

The qualitative responses can provide useful context for interpreting the quantitative data, as they show *what* middle school youth considered when thinking about the importance of space exploration as opposed to the *extent* of importance as demonstrated in the quantitative responses. After viewing the planetarium show, middle school youth responded to an interview question about what, if anything, was important about space exploration (n=54). Many middle school youth shared that human space exploration is important because it leads to new learning (39%), or because humans may need to live on another planet in the future (28%). Learning was a main theme of the show, while colonization was not a focus of the script but rather an application that youth were likely providing from their own background knowledge. Eleven percent reported that they did not know what was important, suggesting that they might not have found space exploration to be important. If middle school youth were often thinking about space exploration in terms of learning and future life beyond planet Earth when considering the importance of space exploration, it may be that there are divergent opinions about how useful learning about space may be for someone on Earth or how likely large-scale human life in space may be. Thus, while a minority of youth found space exploration unimportant and seeing the show made them feel more strongly that it was unimportant, most felt positive about the importance of space exploration, and some became more positive after their experience.

Interest in future behavior: The planetarium and design challenge surveys asked the same set of questions about the extent to which middle school youth were interested in participating in a range of future actions before and after the show and activity. The actions were: checking out news stories about human space exploration, learning about human space exploration at school, learning about science or engineering outside of school, taking college classes about science or engineering, and becoming a scientist or engineer. Whereas the data about learning and importance were skewed, with people often reporting high levels of knowledge and importance both before and after their participation, these data were more evenly distributed across the scale of "not at all interested" to "very interested" in the future activities. This provided more opportunity for participants to report increases, and in some cases the data did show statistically significant change. After the design challenge activity, participants showed a statistically significant increase in their interest in learning about human space exploration at school, taking college classes in science or engineering, and becoming a scientist or engineer.[7] In the planetarium show data, there were small increases in reported interest but none were statistically significant. Thus, there is evidence of meeting this goal for the design challenge but not for the

[6] For the planetarium survey, the percentage of people who strongly agreed that human space exploration is important rose from 36% to 45% and the percentage of people who strongly disagreed increased from 5% to 11% (n=87). For the design challenge survey, the percentage of people who strongly agreed that human space exploration is important rose from 28% to 37% and the percentage of people who strongly disagreed increased from 8 to 11% (n=87).

[7] Learning more about human space exploration at school: Z=-3.276, p=0.001, n=91, r=-0.343
Taking college classes in science or engineering: Z=-3.363, p=0.001, r=-0.353
Becoming a scientist or engineer: Z=-2.453, p=0.014, n=93, r=-0.254

planetarium show. It may be that a planetarium show is better suited for goals around content learning whereas hands-on practice of engineering skills in the design challenge is more associated with seeing oneself as continuing to apply those skills in the future.

Participation in the engineering design process: Two of the evaluation questions about the design challenge focused on the engineering design process. One asked the extent to which participants were observed participating in the process, and the second addressed whether participants recognized their actions as being similar to what engineers do. During observations, about two-thirds of the observed youth demonstrated all four steps of the engineering process, and every observed visitor demonstrated at least one of the steps. In the survey data, 73% of survey respondents agreed or strongly agreed that, during the activity, they did things that were similar to things engineers do (n=95). In a past study of the Design Challenges program, a similar question was posed in an interview format, and, 40% of respondents said that they had done something like what an engineer does (Auster & Lindgren-Streicher, 2013). Comparing these two studies indicates that this project was even better at helping participants recognize that they were doing something like an engineer than the prior Design Challenge work. This may be due to the team's intentional design decisions that emphasized the design process and may also be a reflection of positive training of facilitators who led the activity. Guidance for educators who support the activity is available in the project's Educator Guide.

VI. CONCLUSION

This report describes the summative evaluation of the Museum of Science, Boston's project entitled, *From Project Mercury to Planet Mars: Introducing Engineering and Inspiring Youth through Humanity's Greatest Adventure* project (FPMPM). Funded by a grant from NASA (NNX16AM21G), the project created an immersive fulldome planetarium show and a hands-on engineering design challenge designed to provide high-quality informal engineering education opportunities to underrepresented youth audiences. Data collection for the summative evaluation consisted of surveys and interviews of underserved youth who viewed the planetarium show and participated in the design challenge activity, as well as observations of design challenge participants.

For the planetarium show, the evaluation assessed what participants learned, the extent to which the show increased participants' opinions that space exploration is important, and the extent to which the show increased youth's interest in future activities and careers in engineering and science. There was evidence that the learning goal was met, even though participants reported high levels of prior knowledge. Evidence for this goal includes respondents reporting a statistically significant learning gain about how technology for space travel is changing to support an exploration to Mars (27% strongly agreed before the show and 38% strongly agreed afterwards, n=89).[8] Data from an open-ended interview question further supports the learning goal: all respondents to this question described learning (n=58), with many sharing that they learned about what is involved in human space travel (34%), the engineering involved (22%), or the challenges of human space travel (22%). For the goal about the importance of space exploration, there was evidence that youth found space to be important both before and after the show, but not that the show had increased their sense of importance. During the interview (n=54), many youth shared that human space exploration is important because it leads to new learning (39%) or because humans might need to live in space someday (28%). However, survey questions about this goal showed no statistically significant change. This is likely partially due to the fact that most of the middle school youth agreed that human space exploration was important beforehand (88% of n=87). Of the three planetarium goals, there was the least amount of evidence that the goal about interest in future behavior was met. After viewing the show, middle school youth reported slight but statistically insignificant increases in interest related to activities about science and engineering (for example, the percentage of youth who agreed or strongly agreed they were interested in taking college classes about science or engineering rose from 41% to 48%, n=91). Overall, the data show that the planetarium met its learning goals despite high levels of prior knowledge, that youth felt human space exploration was important both before and after the show, and that there was minimal increase in interest around future activities in careers in engineering and science.

For the design challenge, the evaluation questions addressed goals about the extent to which the activity increased participants' opinions that space exploration is important, increased interest in future actions about engineering and science, supported participants' engagement in the engineering design process, and helped participants recognize that they did things like what engineers do. The data for the goal about the importance of space exploration showed that most

[8] Wilcoxon Signed-Rank Test: Z=-2.01, p=0.04, n=89, r=-0.21

participants agreed or strongly agreed that human space exploration is important (81% before, n=96 and 79% afterwards, n=94), although there were no statistically significant changes after participating in the activity. Thus, the goal was partially met in that youth did feel space exploration was important but the project did not further move the needle by increasing that metric. In terms of interest in future behavior, after the activity participants reported statistically significant increases in interest in learning about human space exploration at school (the percentage reporting they were very interested rose from 13% to 23%, n=91),[9] taking college classes in science or engineering (the percentage reporting they were very interested rose from 16% to 29%, n=91),[10] and becoming a scientist or engineer (the percentage reporting they were very interested rose from 16% to 22%, n=93).[11] This is strong evidence in support of meeting this goal. For engagement in the engineering design process, observations showed that 67% of participants engaged in each of the four steps of the engineering design process (n=62), and 73% of participants "agreed" or "strongly agreed" they did something like what an engineer does (n=95). This serves as a high level of evidence supporting the fact that the project met these two goals.

These findings provide evidence that the project deliverables met most of their goals—albeit some more strongly than others—and also raise questions for future work and study. One consideration arises from looking at the affordances of the two learning experiences. As hypothesized, learning may be a strength of the planetarium format, whereas the design challenge activity appears to be particularly suited to supporting increased interest in future behavior. Planetarians might further explore whether there are different ways to better support increased interest or whether different goals might be better suited for that type of learning experience. For both the planetarium show and design challenge, the data showed modest increases in opinions that human space exploration is important. Future researchers and evaluators studying this type of outcome might wish to explore data collection at multiple points in time, and continued collection of qualitative data to provide context about the ways the learning experiences may have changed their opinions. The measurement approach used in this study may have led to ceiling effects about the importance of space exploration as well as learning, which provide opportunities for future researchers and evaluators to develop different scales that can better capture change. On the practice side, this attitudinal shift may be difficult to produce in brief museum experiences, but it remains an enticing opportunity for future exploration.

As a final reflection, the authors of this report urge continued consideration of how to design informal learning opportunities for underrepresented audiences, and the best approaches for involving these diverse participants in the evaluation process. This process demands the humility of museum professionals in recognizing that the established practices for current museum visitors might not be ideally suited for all audiences, and that there needs to be a willingness to change those established practices. The work of creating experiences for underrepresented audiences may be difficult. Yet, it has tremendous potential to improve museum practices to be more culturally accessible and to promote increases in meaningful learning, attitude change, and behavior that can support a life-long positive relationship with science and engineering.

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[9] Wilcoxon Signed-Rank Test: $Z=-3.28$, $p < 0.01$, $n=91$, $r=-0.34$
[10] Wilcoxon Signed-Rank Test: $Z=-3.36$, $p<0.01$, $n=91$, $r=-0.35$
[11] Wilcoxon Signed-Rank Test: $Z=-2.45$, $p=0.01$, $n=93$, $r=-0.25$

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Planetarium Flash Interview

[To child/ren]: Thanks for filling out that survey! Is it okay if I ask you two quick questions about the activity? **[If yes, proceed to questions; if no, say "Thank you" and let them go back to their group]**

What, if anything, did you learn about human space exploration by watching this show?	What, if anything, do you think is important about space exploration?

Planetarium Survey

Your responses to this survey help us understand the impacts of this program and improve our programs for future visitors like you. Participation is voluntary, and all responses are anonymous.

Questions on this side of the page ask you to think about how you felt **BEFORE** you did this activity today.

1. BEFORE watching this planetarium show, how interested were you in the following activities?

	Not at all interested	A little bit interested	Somewhat interested	Very interested
Checking out news stories (online, TV, radio, and/or print) about human space exploration	☐	☐	☐	☐
Learning about human space exploration at school	☐	☐	☐	☐
Doing science or engineering activities when you're not at school	☐	☐	☐	☐
Taking college classes about science or engineering	☐	☐	☐	☐
Becoming a scientist or engineer	☐	☐	☐	☐

2. BEFORE watching this planetarium show, how much would you have disagreed or agreed with the following statements?

	Strongly disagree	Disagree	Agree	Strongly agree
Work is currently happening for an exploration to Mars.	☐	☐	☐	☐
Technology for space travel is changing to support an exploration to Mars.	☐	☐	☐	☐
Human space exploration is important.	☐	☐	☐	☐
Engineering for space exploration is exciting.	☐	☐	☐	☐

Questions on this side of the page ask you to think about how you feel now, **AFTER** doing the activity.

3. AFTER watching this planetarium show, how interested are you in the following activities?

	Not at all interested	A little bit interested	Somewhat interested	Very interested
Checking out news stories (online, TV, radio, and/or print) about human space exploration	☐	☐	☐	☐
Learning about human space exploration at school	☐	☐	☐	☐
Doing science or engineering activities when you're not at school	☐	☐	☐	☐
Taking college classes in science or engineering	☐	☐	☐	☐
Becoming a scientist or engineer	☐	☐	☐	☐

4. AFTER watching this planetarium show, how much do you disagree or agree with the following

	Strongly disagree	Disagree	Agree	Strongly agree
Work is currently happening for an exploration to Mars.	☐	☐	☐	☐
Technology for space travel is changing to support an exploration to Mars.	☐	☐	☐	☐
Human space exploration is important.	☐	☐	☐	☐
Engineering for space exploration is exciting.	☐	☐	☐	☐

5. What is your age? ___________

9. What is your gender? ___________

Thank you for completing this survey! Your input will help us improve future shows.

Design Challenge Flash Interview

[To child/ren]: Thanks for filling out that survey! Is it okay if I ask you two quick questions about the activity? **[If yes, proceed to questions; if no, say "Thank you" and let them go back to their group]**

What, if anything, did you do in this activity that was like what an engineer does?	**What, if anything, do you feel is exciting about human space exploration?**

From Project Mercury to Planet Mars Design Challenge
Summative Evaluation Observation Form

Use this form according to the associated protocol document, tracking a middle school-aged youth through the design challenge experience. Note down comments she or he makes and describe what happens.

Time start: _______ **Number of designs tested** (tally): ________ **Time finish:** _________

Engineering Design Challenge Activities (check):

Ask/Imagine/Plan

- ☐ Reads or listens to information provided
- ☐ Explores materials
- ☐ Watches someone test a design
- ☐ Discusses the process or ideas
- ☐ Asks a question about the process

Create

- ☐ Builds prototype
- ☐ Tells others how/what to build
- ☐ Starts a new design without testing

Test

- ☐ Tests prototype
- ☐ Observes testing
- ☐ Identifies what happened
- ☐ Identifies pros/cons of design
- ☐ Compares to past performance or record
- ☐ Tests the same design multiple times

Improve

- ☐ Makes changes to design after testing
- ☐ Makes an improvement towards the goal
- ☐ Makes an aesthetic improvement
- ☐ Changes design goal

Notes (What does the youth say and do?)

Design Challenge Survey

Your responses to this survey help us understand the impacts of this activity and improve our activities for future visitors like you. Participation is voluntary, and all responses are anonymous.

Questions on this side of the page ask you to think about how you felt **BEFORE** you did this activity today.

6. BEFORE doing this activity, how interested were you in the following activities?

	Not at all interested	A little bit interested	Somewhat interested	Very interested
Checking out news stories (online, TV, radio and/or print) about human space exploration	☐	☐	☐	☐
Learning about human space exploration at school	☐	☐	☐	☐
Doing science or engineering activities when you're not at school	☐	☐	☐	☐
Taking college classes about science or engineering	☐	☐	☐	☐
Becoming a scientist or engineer	☐	☐	☐	☐

7. BEFORE doing this activity, how much would you have disagreed or agreed with the following statements?

	Strongly disagree	Disagree	Agree	Strongly agree
Human space exploration involves many different engineering challenges.	☐	☐	☐	☐
Human space exploration is important.	☐	☐	☐	☐
Engineering for human space exploration is exciting.	☐	☐	☐	☐

TURN PAGE OVER ➡

Questions on this side of the page ask you to think about how you feel now, **AFTER** doing the activity.

8. AFTER doing this activity, how interested are you in the following activities?

	Not at all interested	A little bit interested	Somewhat interested	Very interested
Checking out news stories (online, TV, radio, and/or print) about human space exploration	☐	☐	☐	☐
Learning about human space exploration at school	☐	☐	☐	☐
Doing science or engineering activities when you're not at school	☐	☐	☐	☐
Taking college classes in science or engineering	☐	☐	☐	☐
Becoming a scientist or engineer	☐	☐	☐	☐

9. AFTER doing this activity, how much do you disagree or agree with the following statements?

	Strongly disagree	Disagree	Agree	Strongly agree
Human space exploration involves many different engineering challenges.	☐	☐	☐	☐
Human space exploration is important.	☐	☐	☐	☐
Engineering for human space exploration is exciting.	☐	☐	☐	☐
During this activity, I did things that were similar to things that engineers do.	☐	☐	☐	☐

10. How much do you disagree or agree with the following statements?

Doing this activity…	Strongly disagree	Disagree	Agree	Strongly agree
…made me want to learn more about how humans might travel to and explore Mars.	☐	☐	☐	☐
…helped me understand the challenges involved in a future mission to Mars.	☐	☐	☐	☐
…made me excited about to think about solutions to the challenges of a future mission to Mars.	☐	☐	☐	☐
…made me more likely to think about becoming an engineer.	☐	☐	☐	☐

11. What is your age? ___________

9. What is your gender? ____________

APPENDIX B: LITERATURE REVIEW

In order to better serve minority and underserved audiences and middle school students, the Research & Evaluation Department conducted a literature review of relevant resources. Information gathered is contained within the table below.

Title of website/resource	**How should we talk to underserved audiences and/or middle school youth about engineering?**	**Link or location**
EdSurge--"Encouraging Diverse Learners in Computer Science and Engineering"	*"Create tasks and projects that are 'low floor, high ceiling'--accessible for students regardless of background knowledge, experience, or their idea of an engineer." *"Offer choice--give students a list of ten requirements and allow them to choose the top three that they will factor into their design." *"Understand that successful engineering is a high-frustration, high-reward activity and communicate with your students often about the maker mindset"	https://www.edsurge.com/news/2016-07-14-encouraging-diverse-learners-in-computer-science-and-engineering
STEM: Volunteer Training: Engaging Middle School Students	*Encourage "growth mindset" *"Map out your first 60 seconds" *"Identify 1-2 key takeaways" *"Define lay friendly ways to describe: **The what:** Key problems/questions **The how:** Processes to find answers/solutions **The why:** Why it matters (and to whom)" *"Select real-world examples, WOW facts, and personal context relevant to your audience" *share about yourself, be passionate *"Ask open-ended questions with multiple answers" *"Acknowledge all answers, including incorrect ones" *"Consider trivia or multiple choice questions to jump start discussions" *"Pause occasionally for understanding -	https://www.energy.gov/sites/prod/files/2015/08/f25/STEM%20Volunteer%20Training%20Engaging%20Middle%20School%20Students%208.13.15.pdf

	reiterate a point or key takeaway- ask for any questions" *"Use accessible, age-appropriate language *"Distill content while keeping it accurate" *Give "specific, positive feedback." -- "Avoid statements such as, 'You are really good at this!'"	
Beyond Blackboards: Engaging Underserved Middle School Students in Engineering	*Questionnaires offered in English and Spanish *Compared results to "Trends in International Mathematics and Science Study (TIMSS)" *1 hour focus groups, encouraged the input of quieter students	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4459751/
Design and Evaluation of a Computer Science and Engineering Course for Middle School Girls	*Five point Likert scale *Administered pre-survey then post survey (see article for survey items) *Mann Whitney’s U test for significance to test change in perception of engineering *Optional interviews were led by participants/semi structured. Allowed them to find issues the participants found most important	https://www.researchgate.net/profile/Paul_Dourish/publication/221537493_Design_and_evaluation_of_a_computer_science_and_engineering_course_for_middle_school_girls/links/0fcfd513950279d2f3000000/Design-and-evaluation-of-a-computer-science-and-engineering-course-for-middle-school-girls.pdf
Engineering Everywhere Curriculum Development	*Survey of 923 participants who finished EE curriculum *Participants asked to rate their current feelings about engineering topics and idea, then retrospectively rate how they felt before the program *Likert Scale rating of 16 statements from 1 to 5 (see pdf for statements) *Statements were divided into categories	https://www.eie.org/sites/default/files/research_article/research_file/eefinalreport.pdf

	(Importance of Engineering, Desire to learn engineering, Enjoyment/Interest in Engineering, Value of engineering to society) *Comparisons were drawn from the average score of responses. *McNamara-Bowker Test run on how easy engineering was for the participant before and after (retrospective)	
Middle school students' attitudes to and knowledge about engineering	*Self-efficacy scale deemed too difficult for middle schoolers to understand *Four part survey "1) the Attitudes to Mathematics, Science and Engineering Scale, 2) the Knowledge About Engineering and Engineering Careers measure, 3) questions about who has talked to them about engineering as a career option and 4) a measure of recent academic performance as well as a short demographic section" *Five point Likert Scale, (0 being I don't know) to catch students who do not have knowledge about engineering, decrease in 0s represents an increase in knowledge of engineering *asked students where they have heard of engineering	http://www.ineer.org/Events/ICEE2004/Proceedings/Papers/105_ICEE2004_Middle_School_Attitudes_(1).pdf
Visitor Studies Today: Measuring the Impact of Interactive Science Programs on Science Learning	*Contains examples of research instruments used to evaluate science learning of elementary/middle school kids in informal learning environments (no particular emphasis on diverse audiences)	http://kora.matrix.msu.edu/files/31/173/1F-AD-289-8-VSA-a0a6c6-a_5730.pdf
Remedial/Summative Evaluation of The Biomedical Technology Exhibition for the Great Lakes Science Center, Cleveland	*More examples of instruments/data collection protocols.	http://informalscience.org/sites/default/files/BioMedTechSummative.90.pdf

Physical Environment	*Whenever possible, use measures that have been tested and validated with groups similar to the groups who will be given the measures. *People's comfort/discomfort in an environment has been found to affect their responses to questions about interest in STEM fields and careers and their feelings of belonging. *Don't mention any gender or race differences that have been found in tests or surveys being used. * Have members of the target population review affective and psychosocial measures for clarity. Ask them what concepts they think are being measured. If what is being measured is obvious and there are sex, race, or disability stereotypes associated with the concepts, consider using a less obvious measure, if an equally valid measure is available. *Ask for demographic information ONLY at the end of measures.	http://beyondrigor.org/
Beyond Rigor	Website outlining best practices for Evaluating STEM programs for minority audiences.	http://beyondrigor.org/RaceEthnicity.html
Designing surveys for children	Concise List of Do's and Don'ts for creating surveys for children	https://austinresearch.co.uk/designing-surveys-for-children/

APPENDIX C: PLANETARIUM FLASH INTERVIEW RESPONSES

What, if anything, did you learn about human space exploration by watching this show?	What, if anything, do you think is important about space exploration?
It was lit. Got to see it turn.	I don't know.
Showed astronauts going around it.	Find out if there is aliens, I hope there is, because I like aliens.
I don't remember all of it.	To learn how different things work.
That it might not take that long to explore Mars.	Helps humans understand how to prevent asteroids from earth. Understand other planets so we can stay alive.
Interesting I guess.	So we know where to go if Earth gets destroyed.
I learned about the satellite. It was built by humans. I thought it was a bunch of rocks, but actually it's a lot of wires. Mars is not, like, all orange, it has craters and stuff.	How to explore new things we have not been to in the world. Explore the whole entire universe.
Learned about how satellite, about what it does. Sometimes people don't make it back.	If earth apparently stopped being normal, [we could] move to another planet in the galaxy and live there.
Mars used to be water. Now it's not water.	If someone gets lost and we've been to space, we could help them get back to Earth.
Time to go to space.	No idea
It's not very easy.	It's good to learn about it and see what is in space.
I forgot	Because it could actually happen to a human. We need to prepare.
I don't know	To find out new things. If something happens to planet Earth, we can move and know that we'll have food and water.
We need to learn about survival in space.	To get there and be safe when you're there.
They need to find a way to get food, water, shelter, survival.	This way we have more info on what's out there. We aren't confined to our planet.
They're building space vehicles to mars. The rocket is about a football field (long).	That you can find new things and show it off to the world.
That we're closer to getting to Mars.	If the sun stops working we need to have a fast escape. We need another planet to go to.
I learned that humans might be able to go to Mars and live on Mars.	Exploring to find new life.
I learned that Mars is pretty far away. All the things we could have are gone.	Plan for future.
It's changing to fit distance to Mars.	Dangers of going.
Learn something new about Mars and its environment.	Some humans got in touch with their inner selves.

People are excited to go to Mars.	Know more about the universe we live in and our place in it and if we're the only intelligent species.
Learned about SLS and that there was once water on Mars.	That if NASA makes it to Mars it's important.
It takes a lot of effort to get to planets in our own solar system. It's hard to think of the effort it would take to visit other galaxies.	Mars.
It's very exciting because it shows what can happen if I was going to be on Mars. I would feel safe because of NASA support.	Like… I don't know.
I forgot.	Seeing what's out there and what planets we can live on.
That it is really… that they've been trying to go to Mars for a while.	The future.
That we're making progress.	Finding new places and hitting checkpoints in our research and technology.
That there is more to learn about it.	We should learn to discover new worlds.
That it's challenging but we're coming to success.	*shrug*
I learned it was really cool.	See what we can do to stop solar radiation.
That we are trying to get to Mars safely.	If we go into space we can make changes.
We are learning more about Mars by going into space… They can see if they can grow food on Mars.	That we find out more.
Mars used to have water 3 billion years ago when it wasn't dried up.	Even though we want to go to Mars, we should be safe about it.
What he said.	Our galaxy is local by environment.
That a lot of people are trying to get to Mars.	Learn what is beyond Mars & other planets and past.
It's crazy, mad joke. Hide & seek in VAB.	Important to wear space suit because of atmosphere.
You can still be successful after all that stuff.	Because experience nobody else has, see different planets, great experience.
Humans trying to get to Mars, figure out what past Mars was like.	If we land on Mars we will learn new things about Mars and Earth.
Space station places to go in space.	Teaches humans about the universe. Gives us advice for being astronauts.
Going to Mars.	There's a chance we could live on Mars.
They are taking time and it's a difficult process but they won't stop no matter what.	Bring lots and lots of food and water.
New tech to travel to Mars to live on Mars.	To be careful.

Very interesting. Mars dried up due to radiation	Be careful, don't do really risky things at Mars and stay warm.
Used to be water on Mars.	Could be another planet for us if, I don't know.
You have to travel a lot.	Finding out how to live on other planet when this one gets way too populated, because that's important.
You have to take a risk.	I don't know. Finding new ways for humans to explore there.
To be excited.	I don't really know.
People are working on stuff for Mars.	Never go without crew.
They're updating it all the time.	Listen to partner.
It takes a lot of fuel to get to Mars or the moon.	Discover and learn more.
It's hard but it can be a success.	Exploring to find out if you can live.
Get used to living on Mars.	You need the right thing to work with.
Ready for anything.	Watch out for solar system.
Three billion years ago there was water and ice on Mars and now it's very dry.	I don't know.
It could be possible for people to live on Mars.	
It's not easy.	
Hard.	
Building things now on Mars.	

APPENDIX D: DESIGN CHALLENGE FLASH INTERVIEW RESPONSES

What, if anything, did you do in this activity that was like what an engineer does?	**What, if anything, do you feel is exciting about human space exploration?**
Kept trying even though we failed.	I agree with him [interviewee DF2].
Tried hard but failed a lot.	Going in outer space and wearing a helmet so you don't die.
Work as a team, share ideas.	Getting out of Earth.
Built things.	I don't know.
[C]: Think, a lot.	[C]: The fact that there's a lot of things out there that people haven't discovered. I want to be the 1st person to discover everything else, like first planet with a body of water.
They design, think about things and design them before they make an actual thing for outer space.	I feel it's exciting to learn about different planets. Find out things we didn't know before.
Putting stuff together.	I don't know.
Building stuff and seeing the length and width of it.	Exciting that you get to learn new things about space and planets.
Build.	Find new planets.
Build like a skyscraper.	Find new planets and humans interact with new species.
Building stuff and learn from mistakes and re-improve what I'm making.	Where you get to go to space and all the different planets.
Build - test the thing we built.	They get to go to planets.
Using other things to make a house.	Exploring new stuff in your life and making new creations.
Build like a rocket.	To me, nothing.
Fixed stuff.	I get to study space.
Design.	That we can find if there's aliens.
Build like a space thing to help get into space	Exploring planets and stuff.
Building the spaceship and making it tall enough.	How you get to explore different planets and learn about them.
Try to do a lot of thinking.	The fact that we can do things to understand about space and exploration.
Like building the rocket takes time and effort.	There's a lot to explore. There might be fun things.
Putting things together and building.	Exploring and finding new things.
Designing things that can help.	Finding out new things we didn't know before.
At first you have to fail to succeed. Can't just have one project.	Travel outside the world, no limit, no barrier.

Build. Build.	Find other life.
About the building.	See if we can live on other planets.
Mini construction.	Learning about stars and planets.
Math.	Explore more planets the one we live on.
Mini construction.	Explore new worlds like Mars.
Probably building.	Exploring and finding new things.
We got a chance to build stuff and use tools.	I think it's exciting because humans can learn about space and if something bad [happens].
We built things and learned that when we build [it] takes a couple [tries].	That you can go into space and learn about stuff.
I just forgot.	One thing is that we could experience other things.
Building and creating stuff.	[How] many challenges it takes.
Planned and built.	How they keep alive there.
Make a shelter.	The textures where they're built.
Making the shelters be there on Mars.	Seems like it’s cool--I like studying space.
Build, improve.	Going into space and discovering new planets.
Build the shelter.	If your finished product was done, how your work paid off.
Brainstorms what to do.	That we build stuff.
Built stuff.	Making the spaceship.
Making the spaceship	

APPENDIX E: REFLECTIONS ON DATA COLLECTION PROCESS

The Mercury to Mars summative evaluation data collection event was overall successful. The project team was able to collect a large amount of data in a brief period of time, from the target sample of this grant. This event was also one step in trying to build a stronger, on-going relationship with the Boys and Girls Clubs of Boston. The primary purpose of the event was to collect summative evaluation data, but it also provided a free evening of activities and dinner at the science museum for a middle school youth who are traditionally underserved in STEM. This type of event aimed to help the project team learn about their activities and engage middle school participants in space-related activities. Below are some reflections about how to plan for more of these types of events in the future.

Logistics of coordinating a large-scale data collection event

- **Coordinating multiple sites:** For this event, the project's research team partnered with local Boys and Girls clubs to recruit middle school participants. A single coordinator from the organization provided our team with lists of potential attendees from each participating site.
- **Arrival logistics:** On the day of the event, it was helpful for our team to have at least one person overseeing check-in and name tags. During this event, a few groups arrived later than anticipated. This required our team to shift the scheduling of dinner and activity stations for particular groups.
    - Lesson: In future events, it is helpful to allow for extra flexibility in arrival timing and for activity transitions. There should be a plan for coordinating late groups so they are able to participate in all parts of the event.
- **Evaluator roles:** For this event, we had a team of nine evaluators helping to collect data across the design challenge activity and the planetarium show.
    - For the planetarium show, two data collectors focused on collecting surveys and doing flash interviews. Additionally, several planetarium staff with human-subjects research training helped to conduct flash interviews as well. We found it helpful to have the participants do their flash interviews in the planetarium before exiting into the main museum space.
    - For the design challenge activity, five data collectors were involved with data collection. Three data collectors focused on observations, while two conducted flash interviews and completed surveys. The design challenge staff were helpful in giving surveys to participants once they finished the activity.
    - Ideally, there is a person who can float around the event to help where needed or provide directions from one location to the next.
- **Feeding participants:** This event took place from 4-7pm on a Wednesday evening. Due to the length and timing of the event, our team wanted to make sure that participants were fed during their time at the Museum. Coordinating food through internal catering was expensive and challenging, particularly when all groups did not arrive on time and participants ate more food than initially anticipated.
    - Lesson: Talk through contingency plans for coordinating groups who are running late. In future events, box lunches may work better for middle school aged groups (rather than buffet style) so that these meals can be prepared ahead of time and food estimates are easier to approximate. Additionally, staff from the project or research team should monitor the

meal station in case logistics change or catering team has additional questions.

• **Large group dynamics:** We recognize that large groups often function differently than family groups in the museum. We found that the Boys and Girls club functioned similar to school groups that visit the museum. This group fit the target sample for this grant, but it should be noted that these groups may be different from typical museum-going families at MOS. It is also important to note that individual sites within the same organization might have different cultures or operate differently when visiting the Museum. Recognizing this ahead of an event can help with planning.

• **Indicating consent:** When possible, it is helpful to obtain consent forms in advance. When that is not possible, participant nametags should be marked to indicate consent upon arrival. For this event, we used stickers to keep track of who had provided consent.

- Lesson: In future events, using stamps instead of stickers on nametags might be easier, as it less likely that the stamp can go missing from participant nametags during the event.

Data collection for a large-scale data collection event

Collecting observations: For the design challenge data collection, our team experimented with having observers track two students at the same time to maximize the number of observations captured. Sometimes partial observations were captured, but only complete observations were included in the analysis for this project.

- Lesson: Even if you have a large number of people at an activity, you can only observe up to two visitors at one time.

Administering multiple surveys: Some participants were confused when filling out multiple, similar surveys. If participants had filled out the survey at one activity, some were less inclined to fill it out a second time for a different activity because they felt they had already done the survey.

- Lesson: Perhaps telling participants ahead of time that the surveys are similar in format but capturing data about different activities could alleviate confusion. In future events, participants could receive a stamp or sticker after completing each survey in order to better track survey completion.