Facilitation Research for Engineering Design Education (FREDE)

Research Report

Report Written by Alexander Lussenhop, Ryan Auster, and
Anna Lindgren-Streicher
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Science Park
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Research and Evaluation Department
Museum of Science
Science Park
Boston, MA 02114
(617) 589-0302
researcheval@mos.org

EXECUTIVE SUMMARY

This IMLS-funded study sought to examine the impact of educator-facilitation on engineering attitudes and self-efficacy of children in Design Challenges activities. Using a quasi-experimental design with statistically comparable pre- and post-experience groups, researchers collected observation, interview, and survey data to address the following research questions:

1. Do visitors' perceptions of engineering activities improve as a result of the facilitated Design Challenges experience?
2. What aspects of the interactions between museum educators and Design Challenges visitors contribute to changes in visitors' attitudes toward engineering and engineering self-efficacy?
    a. Does the number of educator-facilitated interactions with visitors affect attitudes or engineering self-efficacy?
    b. Does the point within the engineering design process at which the interactions occur affect attitudes or engineering self-efficacy?
    c. Does the content/type of interaction affect attitudes or engineering self-efficacy?
3. What are the primary motivations for on-going participation in the activity?
4. What other factors influence the visitors' perceived success during the engineering process?

Data were collected from a total of 304 family groups (152 pre-activity and 152 post-activity) with a focus child between the ages of 7 and 14. The study included three different engineering Design Challenges: Bobsleds, Boats, and Claw. Observation data focused on interactions between educators and participants. Across the entire post group, researchers observed over 1,000 interactions between visitors and facilitators at the Design Challenges activities.

A number of findings emerged from these rich data. Participants who had at least one encouraging check-in with an educator stayed 8 minutes longer, tested close to two additional designs, and had about four additional interactions with an educator, on average, than visitors who had no encouraging check-ins. All of these differences were statistically significant. Furthermore, each additional interaction with a facilitator offering encouragement or simply checking in was found to significantly increase self-efficacy scores by one-half point; that is, children with more encouragement from educators were more likely to say that they were capable of doing engineering design activities. This is particularly interesting as it provides additional support and context for a finding from an earlier study on educator interactions at Design Challenges (Kollmann & Reich, 2007). This also highlights the importance of encouragement for other museum educators who facilitate similar design-based activities.

In addition, from inductive coding of the interview data, researchers also found that children who tested multiple designs were primarily motivated to do so because they wanted to improve their designs, and that parents usually rated their children's success based on whether they felt their child had engaged in the engineering design process (not just the success of the child's design).

Future research could focus more on the topic of encouragement, such as parent facilitation and encouragement or visitor perceptions of encouragement from educators.

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I. INTRODUCTION

Founded in 2003, Design Challenges is a facilitated drop-in activity that engages families and school groups in the engineering design process as they iteratively plan, create, test, and improve a prototype to address the challenge of the day. Program staff have developed 19 different challenges, 12 of which are currently being used, such as designing the fastest or slowest possible bobsled, constructing an arcade claw that will pick up as many toys as possible, and creating a trampoline to make a golf ball bounce very high or very low (the last two activities were developed using IMLS support through *Engaging Girls in Engineering Design* MA-04-10-0494-10). Since it began, the program has served over 650,000 visitors.

In addition to successfully engaging a large number of visitors, a summative evaluation conducted after the program's initial implementation provided evidence that the program successfully engaged visitors in the engineering design process (Ask-Imagine-Plan-Create-Test-Improve) and that over 90% of children who participated in the program connected the activity to what engineers do in their work (Sloat Shaw, et al., 2005). A 2012 summative evaluation focused on girls showed high levels of engagement from visitors, who, on average, stayed at the activity for over 15 minutes and engaged in more than three cycles of the engineering design process (Auster, 2013).

Since the opening of this hands-on engineering space, the Research and Evaluation Department at the Museum of Science has repeatedly partnered with Design Challenges educators to study visitors' engagement, learning, and interest in future engineering activities, including studies related to girls' engagement and the effects of competitive aspects on participants (Beyer & Auster, 2013). The basis for this study, Facilitation Research for Engineering Design Education (FREDE), was the Design Challenges staff's expressed desire to better understand which facilitation techniques result in a positive, engaging visitor experience. The research questions were chosen to give educators an understanding of which aspects of facilitation in a design-based activity lead to increases in visitor learning. The following research questions were addressed during this study:

1. Do visitors' perceptions of engineering activities improve as a result of the facilitated Design Challenges experience?
2. What aspects of the interactions between museum educators and Design Challenges visitors contribute to changes in visitors' attitudes toward engineering and engineering self-efficacy?
    a. Does the number of educator-facilitated interactions with visitors affect attitudes or engineering self-efficacy?
    b. Does the point within the engineering design process at which the interactions occur affect attitudes or engineering self-efficacy?
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3. What are the primary motivations for on-going participation in the activity?
4. What other factors influence the visitors' perceived success during the engineering process?

Study background

Design-based activities and spaces dedicated to them are becoming more common in science centers and other informal learning institutions. The proliferation of design-based activities in museums reflects an increased focus on engineering, technology, and the design process in different educational environments. For example, an explanation of conceptual shifts in the Next Generation Science Standards explains that the new standards seek to "[raise] engineering design to the same level as scientific inquiry in classroom instruction when teaching science disciplines at all levels" (NGSS Lead States, 2013). The National Research Council's National Science Education standards also include engineering amongst science disciplines (National Research Council, 1996).

Research conducted on design-based activities in formal education environments further suggest the educational promise of the open-ended approach to these activities embraced by many museums. For example, one line of study within engineering education focuses on the notion of productive failure, which posits that under certain conditions learning through struggle and invention can be more effective than direct instruction (Collins, 2012; Kapur, 2008). Additional research has demonstrated that, indeed, productive failure often leads to increased learning, but that this may not necessarily result in successful performance (hence the term productive failure); without self-regulation or structured intervention, the productivity of failure may result in the formation of bad habits or misconceptions (Hung, 2009). This suggests that, in order to take advantage of the possible positive impact of productive failure within design-based activities, skilled facilitation may be needed. Although these studies have been limited to school-based learning environments, the findings suggesting the efficacy of the approach of productive failure are likely to extend to the creative, design-based activities found in many museums.

A number of other research efforts have recently focused on design-based activities including an IMLS-funded research project being conducted by the Children's Museum of Pittsburgh and New York Hall of Science, focusing on family interactions in museum-based maker spaces, and the NSF-funded GRADIENT project from the Science Museum of Minnesota and Purdue University, which is exploring gender differences in parent-child interactions during engineering activities in informal settings. However, one area of major importance related to this type of activity remains unexplored: the facilitation provided by expert educators. Most engineering or maker programs rely on the expertise of facilitators to introduce the activities to visitors, help them explore materials and goals, and offer suggestions and encouragement as they test and redesign their prototypes. Indeed, the previously cited research on productive failure suggests that facilitation may play a key role in ensuring the efficacy of these activities. Although several research studies have examined the effect of staff facilitation within a museum setting (e.g. Pattison & Dierking, 2012; Mony & Heimlich, 2008), none of these studies have examined the hands-on, open-ended, materials-rich context unique to design-based activities. This gap in the research in the field as well as interest from Design Challenges staff at the Museum of Science, Boston inspired this research on the effects of facilitation at an engineering design activity on engineering attitudes and self-efficacy.

Attitudes toward engineering and engineering self-efficacy were chosen as measures because prior research exists establishing both as valid indicators of future learning. Most recently, positive attitude toward science was linked with higher science achievement using advanced psychometric techniques in the 2011 Trends in International Mathematics and Science Study (TIMSS), which looked at achievement in over 50 countries worldwide. More specifically, this robust international study provides “very powerful evidence showing that within countries students with more positive attitudes toward science have substantially higher achievement, and the results from TIMSS 2011 are consistent with previous assessments,” (Martin, et al., 2012). Domestically, the Program in Education, Afterschool & Resiliency (PEAR) based at Harvard University has developed a number of measurement instruments dedicated to helping assess constructs such as engagement and attitudes to gauge learning in informal science settings. The research that prompted this initiative has demonstrated the critical importance of out-of-school experiences driving motivations to learn *within* school settings (Osborne, et al., 2003; Osborne & Dillon, 2007).

Self-efficacy is an individual’s perception that he or she can do something. In assessing self-efficacy, an individual may take into account factors such as general self-esteem and perceptions of his or her own competence relative to others, as well as overall self-concept, prior experience, and verbal reinforcement when assessing capability for future task performance (Bandura, 1977, 1997; Pajares, 1996). Importantly, self-efficacy has been shown to be a highly effective predictor of student motivation and learning (Schunk, 1985; Zimmerman, 2000). Recent research has also demonstrated that self-efficacy can be influenced by feedback from others. One such type of feedback is self-regulatory feedback, designed to help learners develop and trust their own metacognitive strategies for creating their own reflective internal feedback processes as they engage independently in tasks (Butler & Winne, 1995; Zimmerman, 1995). Learners who are effective and confident in their abilities to self-evaluate and self-regulate are generally more successful and persistent in learning tasks, positively reinforcing improved self-efficacy (Paris & Paris, 2001; Schunk & Zimmerman, 1997).

Tying these unique measures of learning together in this study are the Design Challenges engineering space and the educator-facilitated activity itself. Research in the field has shown facilitative practice to be a continual process of inquiry (Mackewn, 2008) and that facilitated practices of inquiry are in turn an integral part of the learning experience at many museums for visitors (Pattison & Dierking, 2012). Likewise, previous work has illuminated the engineering process as a fairly limited conception to many elementary-aged children (Kollmann & Reich, 2007; Lachapelle, et al., 2012). This study aims to build on this previous work by studying the relationship between the facilitated process of engineering design through the informal learning measures of attitudes toward engineering and self-efficacy.

II. METHODS

Data were collected over a one-year period from May 2014 to May 2015. The study employed several methods, including observations, interviews, and surveys. Data were collected from both adults and children. The study methods and their associated instruments are discussed below.

STUDY SET-UP

To investigate the effects of the facilitated Design Challenges experience on visitors' perceptions of engineering activities and engineering interest and self-efficacy, the FREDE study employed a quasi-experimental, mixed-methods design. Although subjects could not be randomly assigned to control and treatment groups, the study was set up to create a statistically comparable control group to allow for the exploration of these effects using strategies that had been used in another MOS Design Challenges study in the past (Auster & Lindgren-Streicher, 2013). This comparison group, hereafter called the pre group, was approached and interviewed before they began the Design Challenges activity, while the treatment group, hereafter called the post group, was observed for the duration of their participation and then approached. This pseudo "matched pairs" design enabled researchers to create a random purposeful sample of both boys and girls across activities, while eliminating the threat to response reliability by preventing the same children from taking both pre (control condition without the facilitated experience) and post (treatment condition having had the facilitated experience) instruments.

To investigate the effects of facilitation across a range of activities, three different Design Challenges were included in the study. These three involved building a bobsled, an arcade claw activity, and a boat (called "Echo Base Bobsleds," "Ships Ahoy!" and "Create-A-Claw," and referred to by shortened names here for simplicity). In the Bobsleds activity, visitors could choose between a flat or bumpy track and building a fast or slow bobsled by varying the fabric on the sled's underside or the amount of weight it carried. In the Claw activity, visitors built a gripping arcade claw and could choose between trying to pick up as many hard or soft toys (alligators or flamingoes). In the Boats activity, visitors could choose between building a fast boat or one that could ferry the most toy gems ("treasure") all the way down a water track.

The Design Challenges activities are very popular, and there are natural variations in crowding during different times of the week, day, and year. Recognizing that educators' facilitation techniques may be very different on a busy, crowded holiday afternoon versus a slow, quiet weekday morning, data collection was scheduled in an attempt to create balance between mornings and afternoons and weekdays and weekends. Data collection was also scheduled during school vacation weeks and holidays.

Other study considerations included age and gender of participants. The Design Challenges program is geared toward children who are in 4th through 10th grade, and activities are mapped onto state and national curriculum standards for these grades. Likewise, children were sampled such that their ages matched those grade levels, meaning that data collectors sampled children who were roughly ages 8-14. However, Design Challenges frequently attracts older and younger children, and children just outside that age range were occasionally included in the study sample as well. Data collectors also sampled an equal number of boys and girls. Though participants in the Design Challenges activities frequently participate in groups, one focus child was sampled based on age and gender. This focus child was sampled by selecting the only eligible child within a group, or, if there was more than one, the first eligible child who approached the counter. Due to the inclusion of parents in the study sample and the necessity of obtaining parental consent for IRB guidelines, only family groups were included in the sample.

INSTRUMENTS

Instruments for different data collection methods were developed for children and adults as well as the pre and post groups. The instruments were developed in collaboration with Design Challenges staff and informed by previous Design Challenges research. Where possible, previously-used instruments were given study-specific modifications to allow for the possibility of comparisons, though not inferential analysis, between studies.

Observations

A key component of this study on facilitation was observing and recording visitors' interactions with Design Challenges educators, as well as tracking overall engagement in the activity. Facilitation was defined as any verbal interaction between the focus child and a Design Challenges educator that was about the engineering activity. On the observation instrument, data collectors tracked several aspects of each interaction: number (i.e. how many interactions the child had with educators), length, point in the engineering design process, initiator, iteration number, and content of the interaction as close to verbatim as possible. Measures of overall engagement included total stay time at the activity along with the final number of designs tested. Every time a child made a change to their design *or* switched the test condition (e.g. switched their bobsled from a flat track to a bumpy track) was considered a new iteration of their design.

Data collectors began counting the number of interactions between the child and an educator after the end of the introduction. Any quick, simple follow-up question at this time was considered to still be part of the introduction and not counted. Interactions were timed using a stopwatch, or in some cases, estimated by the data collector. At the start of an interaction, data collectors recorded who initiated it—either the child, educator, parent, or other group member. In general, the person who approached or spoke first was considered to have initiated the interaction. An interaction was considered to have ended when the focus child or educator disengaged by walking away, stopping the conversation, or in the case of interactions in the pre-test phase, approaching the educator to test a design.

Visitors to the Design Challenges activity, with rare exceptions, will have at least one interaction with an educator. Upon the visitor's approach to the table, educators give them a short introduction to the activity, its rules and format, and give them starting materials. This interaction has semi-standard content and length, through individual educators may modify it somewhat. Because the introduction was required to start the activity, it was not counted in the overall facilitation count for study subjects. However, the introduction was timed, and data collectors tracked its basic content to monitor which of the standard introduction topics were discussed.[1]

Data collectors also recorded the point in the design process at which facilitation occurred. Design Challenges staff often use a model of the engineering design process that includes: **Ask** a question, **Imagine** the solution, **Plan** a design, **Build** the design, **Test** the design, and **Improve** the design. Due to the nature of the observed activities and their emphasis on the testing phase, the facilitation study used a modified process model: Ask/Imagine/Plan, Build, Pre-Test, and Post-Test. Pre- and post-test phases were included because post-test interactions are important to Design Challenges staff and because previous research has suggested that facilitation at this phase is especially key for visitor persistence (Kollmann & Reich, 2007). Separating these phases allows researchers to investigate the effects of post-test facilitation. The Boats activity was unique in that it had one extra phase, the sink/float test. The sink/float phase was added to the Boats activity as a way for visitors to test if their boats would float before going to the testing track. There was usually an educator interaction in this phase, as the sink/float table was staffed.

Child interviews

Children in both the pre and post groups were interviewed about the Design Challenges activity and their perception of design activities in general. Before participating in the activity, children in the pre group were asked why they decided to come to the Design Challenges activity, what they were hoping to do, and how they perceived their own skills at designing and building things. They were also asked about previous experience with Design Challenges.

After participating in the activity, children in the post group were asked about times when they got stuck or confused, about their interactions with educators, and, if they tested more than once, and their motivations for ongoing participation. Similar to the pre group, children in the treatment group were also asked about their perceptions of their own skills at designing and building and previous experience at Design Challenges.

Child surveys

After the interview, children in the pre and post groups were given a brief survey to complete. Children rated their excitement to participate in Design Challenges (pre group) or their engagement in the Design Challenges activity (post group). Children rated their excitement/engagement on a 4-point scale (for example: Not excited at all, A little excited, Very excited, Super excited!). Children in the post group also rated their interest in future engineering activities, such as "I would like to do this design activity again." To collect these data, children were asked to rate on a 4-point agreement scale (Really Disagree, Sort of Disagree, Sort of

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[1] The average time for the introduction was 1 minute and 11 seconds, but was as short as 13 seconds and as long as 4 minutes and 12 seconds. The following topics were covered in this introduction: Activity Goals: 96%, Rules: 92%, Record Board: 75%, Magnet/clean-up (intro): 91%, Asks simple questions: 37%, Materials: 96%, "Engineer": 55%, Connects to prior experience: 16%. Afterward, 87% of visitors returned their materials, and 81% got a magnet.

Agree, Really Agree). Because these questions related directly to the Design Challenges experience they had just had, only the post group answered them. However, both pre and post groups rated their agreement with other interest statements such as “I would like to be an engineer” or “I would like a job where I design and create things.” Children in both groups also answered questions about their engineering self-efficacy, such as considering how successful they might be at participating in a different engineering Design Challenge that they may not be familiar with. They were asked to rate their agreement with statements such as “I can build a mini-bobsled that can race down a track.”

Adult interviews

In the post group only, parents of focus children were interviewed while their child filled out the survey. Adults were asked about how successful they thought their child was at the activity and why, if they took a hands-on approach to designing and building, their perceptions of the educators’ interactions with their child, and about their own career and whether or not they were scientists or engineers.

Adult surveys

In the post group only, adults were given a short survey to fill out while their child was being interviewed. On a 5-point scale where 1 was “I do not know” and 5 was “I am confident enough to explain it to others,” adults rated their perception of their own knowledge of engineering by answering questions such as, “I know what engineers do.” On a 10-point scale, where 1 was “No interest” and 10 was “Extreme interest,” adults rated both their interest and their child’s interest in science and engineering. Design Challenges staff also wanted to know whether the children involved in the study were homeschooled, so adults were asked this question as well.

SAMPLE INFORMATION

The overall sample was comprised of 304 subjects, roughly balanced across gender and activity. Groups were purposefully sampled in order to balance the number of boys and girls, as well as the number of subjects participating in the three different activities.[2]

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[2] An *a priori* power analysis was conducted to examine the relationship between desired sample size and effect size, given the logical constraints of the study in terms of both data collection hours and finances. The balanced design above, with 150 participants in both pre and post groups, achieves an approximate power of 0.84 for analyses looking for medium-low effects ($\omega^2 = 0.2$). This means that for changes in outcome measures (i.e., attitudes, self-efficacy) on the order of 20%, a total sample size of 300 will detect differences that truly exist roughly 80% of the time.

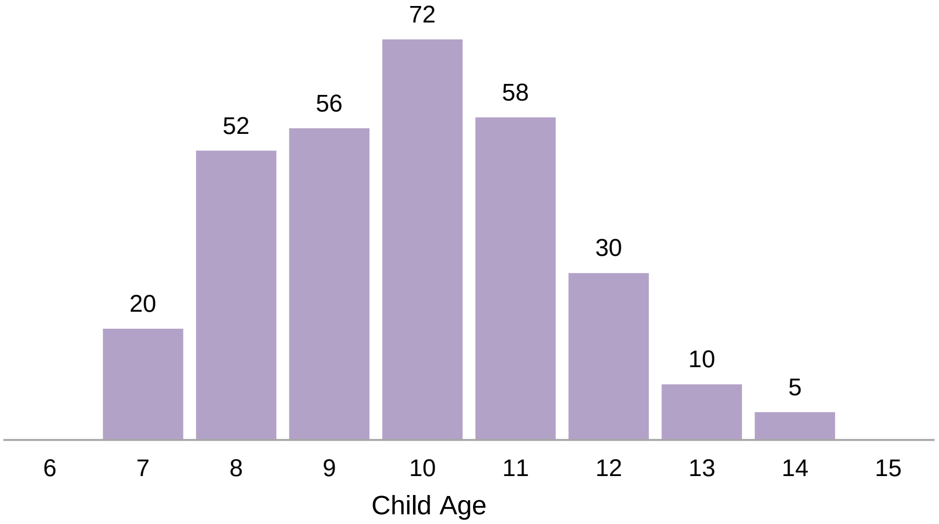
Table 1: Design of experiment (n=304)

Girls (*n*=153)					
Bobsleds		Boats		Claw	
Pre	Post	Pre	Post	Pre	Post
25	25	25	26	27	25
Boys (*n*=151)					
Bobsleds		Boats		Claw	
Pre	Post	Pre	Post	Pre	Post
25	26	25	25	25	25

Ages of participants

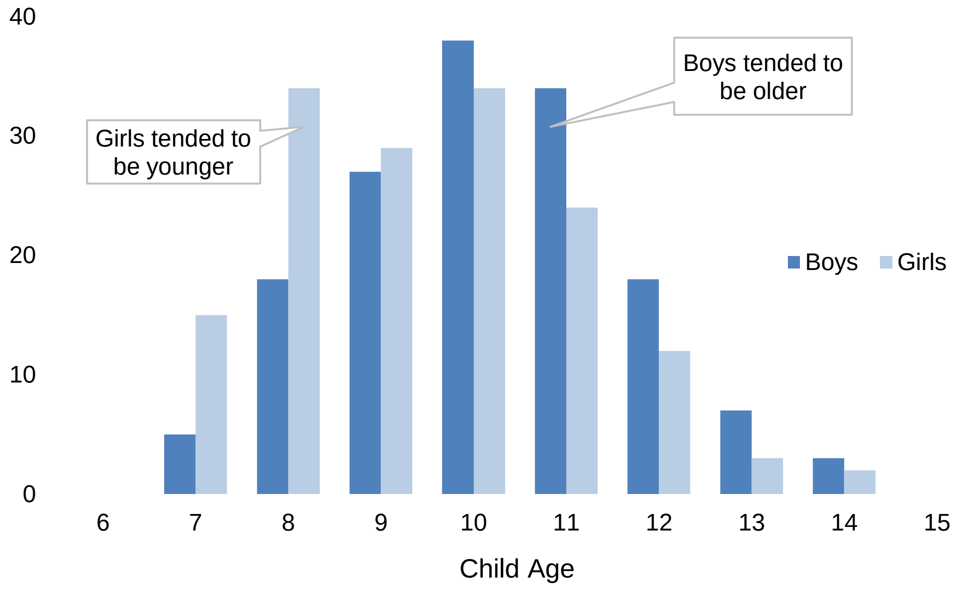
Data collectors targeted children who appeared to be in the 8-14 age range. In practice, study participants ranged from 6-14 years old. However, any recruited subjects who were younger than 7 were excluded from the sample. In addition, one participant's age was missing. About 94% of study participants were in the target range of 8-14, with 20 participants (6.6% of the 303 participants with complete data for age) being 7 years old. The figure below shows the breakdown of ages for the entire sample, including pre and post.

Figure 1: Ages of all participants (n=303)



When looking at the age breakdown between boys and girls, the mean age of boys was 10.17, while the mean age for girls was 9.48. This difference was statistically significant and appears to be due to the fact that there were more girls below the age of 10, as well as more boys aged 10 and older in the sample. The figure below shows these differences.

Figure 2: Boys and girls differed in age* (n=303)



$* \ MWU = 8471.5, p < .001.$

Case studies

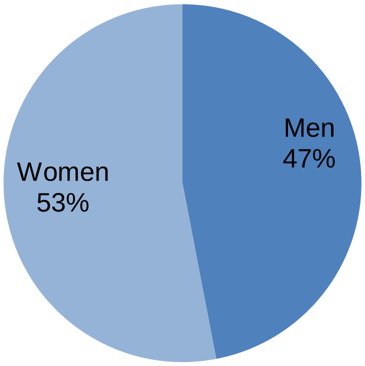
There are also two outliers in the data that need to be considered, one boy and one girl. The boy was 10 years old, built 20 iterations of his boat design, and stayed at the activity for 86.2 minutes. The girl was 9 years old, built 32 iterations of her bobsled design, and stayed for 61.2 minutes. These stay times and numbers of iterations were much higher than those in the rest of the sample. To get a better sense of typical stay times and numbers of iterations, these outliers were removed and descriptive statistics recalculated. Brief case studies to describe these outliers can be found in Appendix E.

For all subsequent analyses, these influential data points have been removed from the data (overall post *n*=150).

Parent information

As noted above in the discussion of instruments, for the post group only, a parent or guardian was interviewed and surveyed, meaning that researchers have some demographic information related to parents as well. The gender breakdown for parents was close to half-and-half men and women:

Figure 3: Parent gender (n=150)



The Design Challenges educators were interested in parents' science and engineering backgrounds, as well as whether or not they homeschooled their children. Survey responses showed that 4.6% of parents (7 adults) homeschooled. Parents also had a variety of educational and career backgrounds. Parents were asked to self-identify as having a low, medium, or high background in science or engineering. If they said medium or high, they were asked if they had a degree or career in science or engineering. Most adults said they had a medium background in science or engineering. About 16% of parents identified themselves as having engineering degrees or careers.

Figure 4: Parents most often said they had a "medium" background in science or engineering (n=150)

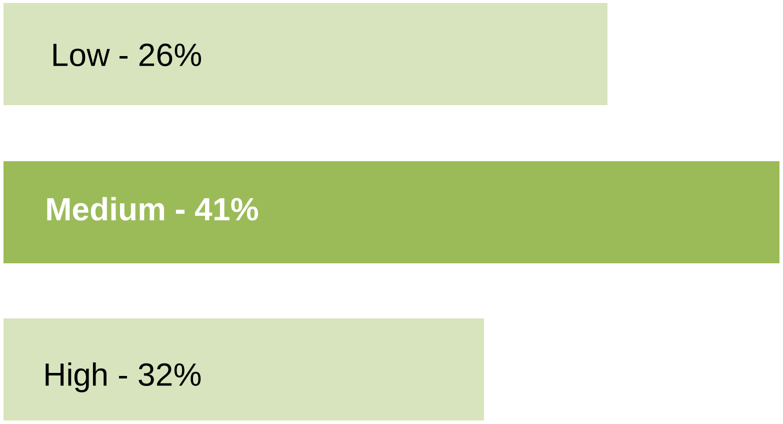
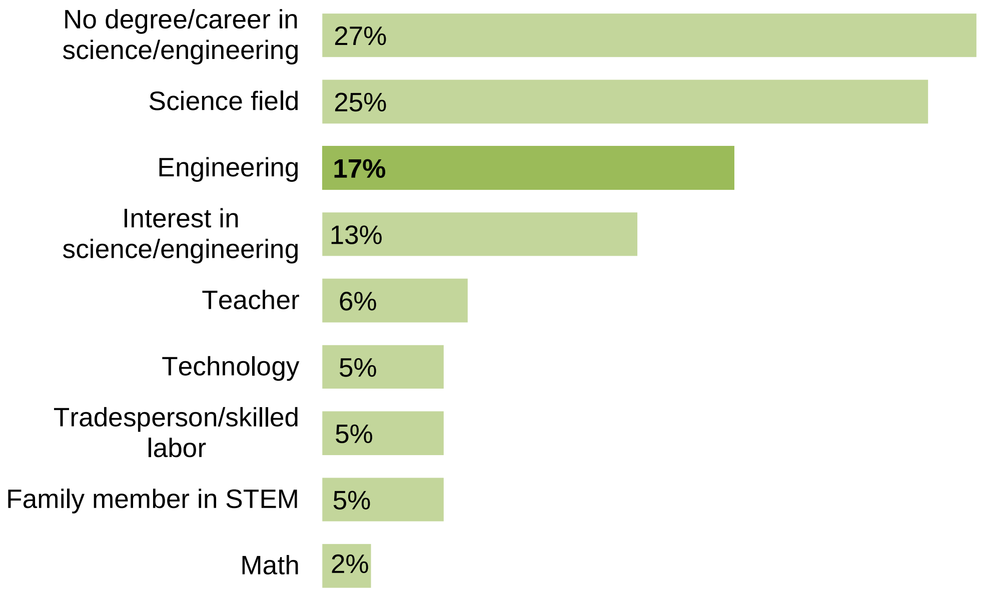


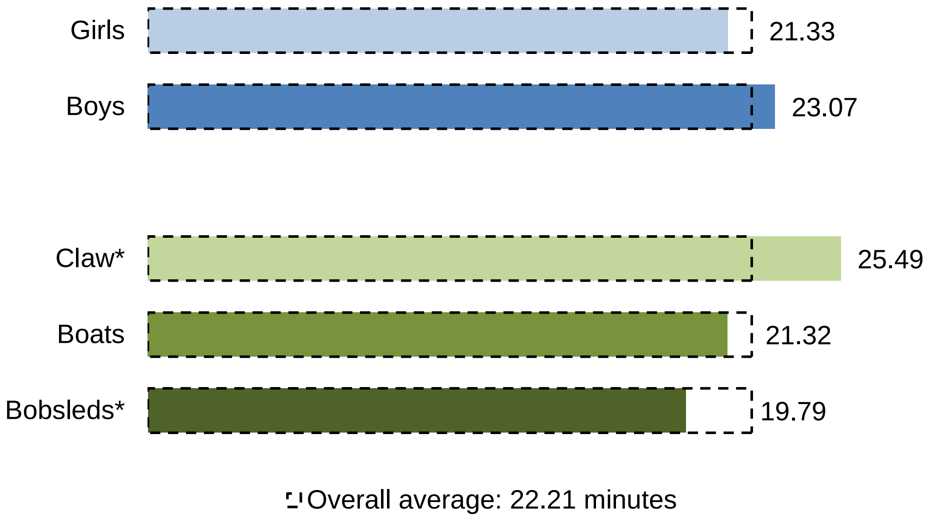
Figure 5: About 17% parents identified themselves as having engineering degrees or careers (n=150)



Descriptive statistics

Visitor stay time has been consistently tracked across several Design Challenges studies. In the prior Design Challenges study Assessing Competition in Engineering (ACE), average stay time was 20.2 minutes, and visitors completed an average of 5.1 iterations of their bobsleds (Beyer & Auster, 2013). Data collected for the FREDE study indicate that visitors across the three challenges stayed for an average of 22.2 minutes and completed 3.8 iterations of their bobsled, boat, or claw design. Below, the figure shows the differences in average stay time in minutes between girls and boys and between activities. The dotted line represents the average stay time across the entire (post) sample. Gender differences were not statistically meaningful; this is consistent with findings from Auster and Lindgren-Streicher's (2013) summative evaluation of Design Challenges activities, but in contrast to ACE in which gender differences in stay time were observed. However, there were statistically significant differences in stay time by activity, specifically between participants in the bobsled and claw Design Challenges activities.

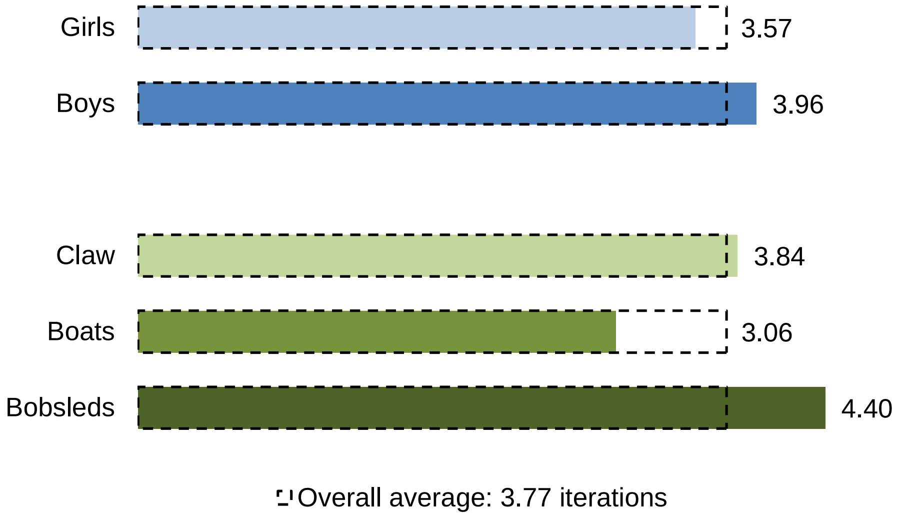
Figure 6: Visitors spent over 22 minutes at Design Challenges, on average (n=150)



* Claw and bobsleds significantly differed. $MWU = 930.0, p = .027$.

The figure below shows the average number of iterations for girls and boys and between activities. The dotted line represents the average number of iterations across the entire (post) sample. There were no statistically significant differences between gender or activity groups.

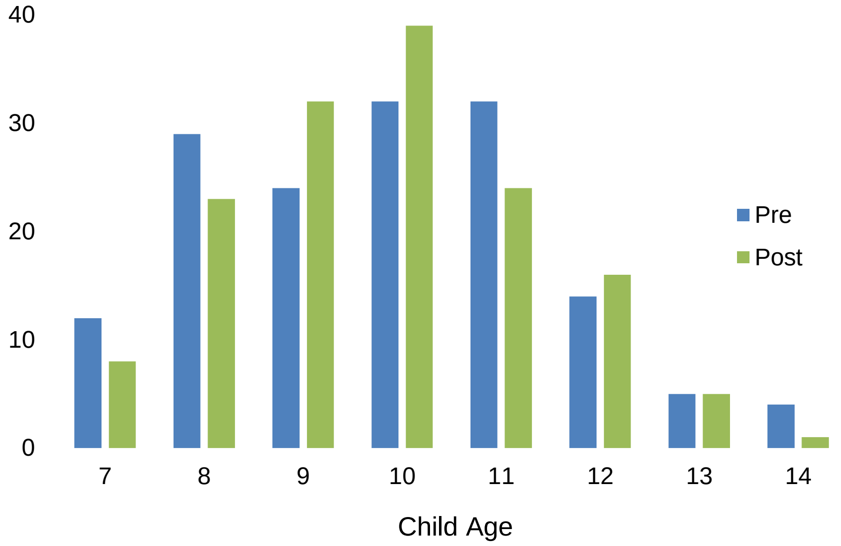
Figure 7: Visitors built close to four designs, on average (n=150)



Pre and post comparisons

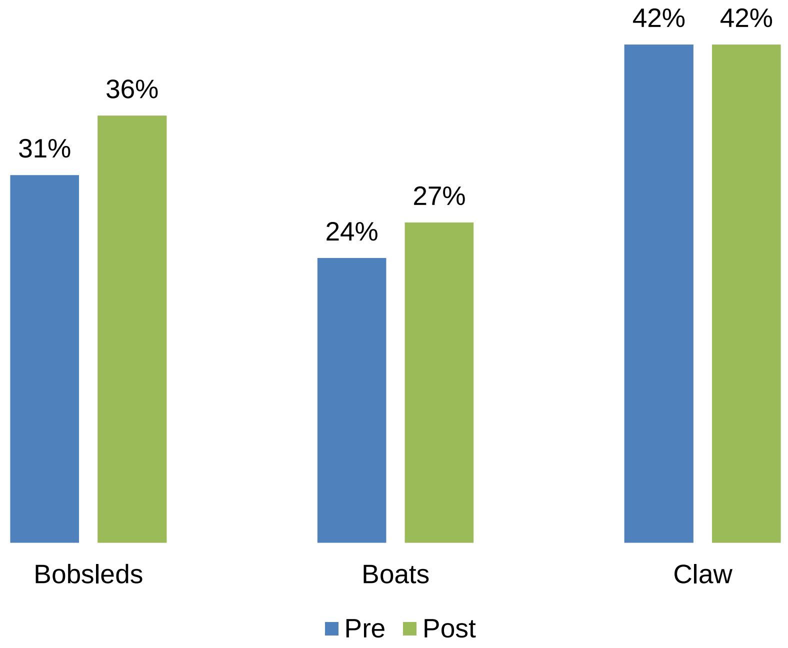
There were no statistically significant differences between the pre and post groups, including their ages. This finding held when looking across the three Design Challenge activities and across boys and girls. The chart below shows the age breakdowns of the pre and post groups.

Figure 8: Children's ages, pre and post groups (n=150)



Pre and post participants were also asked whether they had participated in a Design Challenges activity before and analyzed to ensure pre/post group comparability. Overall, 41% of the pre group (62 participants) and 38% of the post group (55 participants) had participated in a Design Challenges activity before, results which confirm there were no differences between these two conditions in terms of prior experience with Design Challenges ($MWU = 10961.0, p = .570$). The most common activity for prior participation was the Claw activity, with 42% of pre and post participants who had previously done a Design Challenge saying that they had done the Claw challenge before (26 people in the pre group and 23 in the post group).

Figure 9: Previous Design Challenges activity, of those with prior experience (n=117)



Data analysis

Due to the mixed qualitative and quantitative nature of the data, multiple analytical techniques were used. An initial examination of the quantitative data revealed most to be skewed – for example, observational data such as stay time and number of designs built have a natural floor of 0 and no upper limit (except for that imposed by the operating hours), while many of the survey responses were bunched at the top end of the scale, displaying a negative skew. Because of this, the non-parametric Mann-Whitney U test was used rather than the related samples *t*-test to examine the impact of the facilitated Design Challenges activity on individual attitudes toward engineering and engineering self-efficacy (indicated by the test statistic, MWU). Chi-square analyses were also conducted on categorical survey data to explore the effect of facilitation, including number, design phase, and content of facilitated interactions (indicated by the test statistic, χ^2). Lastly, ordinary least squares (OLS) regression was employed to examine the differential impact of various aspects of the observed visitor-educator interactions on engineering self-efficacy or attitudes, while accounting for variance otherwise explained by background characteristics such as age and gender of participants. For all visuals below displaying statistically significant differences between groups, titles include an asterisk (*) and the statistical information is indicated below the figure.

Analyzing differences between groups for 4-point Likert scale responses can be fairly limiting, however, so to increase the variance among individuals and create a more nuanced analysis, several composite measures were created, aggregating responses across survey items. Specifically, three self-efficacy questions were summed to create a self-efficacy index score, and three attitudes toward engineering items were summed to create an attitudinal index score. These survey items can be seen on the instrument included in Appendix B: question 3, items e, f, and g for self-efficacy, and questions 1 and 3, letters a and b, for attitudes toward engineering.

Finally, content analysis was performed on observational and interview data to enable additional tests to be performed to look specifically at the variations in engineering activity facilitation and their effects on attitudes toward engineering and perceived self-efficacy. These analyses focus specifically on the content of the educator/participant interactions as well as the timing of the facilitation within the engineering design process.

Across all the post subjects, data collectors recorded over 1000 interactions. To make sense of these, data collectors decided to code them into different categories using inductive coding, where broad themes become the codes for the data. To establish broad categories, researchers used preliminary analysis undertaken prior to the grant's associated professional development workshop as well as conversations with Design Challenges educators. After preliminary analysis, researchers determined that the interactions between educators and visitors usually fell into one of four categories: logistics, design process, testing a design, and encouragement.

After conducting this preliminary analysis, researchers spoke with Design Challenges educators. They pointed out that the engineering design process includes testing, and as such, the category of testing could be enveloped into the category related to the design process. In the final data set, nearly every interaction fell into one of those three categories: logistics, design process, and encouragement. Exceptions included interactions that were completely inaudible or so minimal as to be irrelevant (i.e. an educator handing materials to a child and saying, “Here.”) Within those broad categories were several smaller ones. For example, within the “design process” umbrella code, there were categories to indicate a general category as well as “Design advice and/or feedback,” “Testing,” and “Testing result.”

Interview data were also coded using a mix of deductive coding and inductive coding. Inductive coding, where broad themes become codes for the data, were used in most cases. Deductive coding, where coding categories are developed in advance, was used when previous studies had asked the same interview question and the previous codes could be used to code the new data. These qualitative data also helped to establish both internal and external validity, providing a justification for any inferences about the intervention and detailing the context of the environments suitable for generalizability.

Limitations

Although this type of quasi-experimental design uses statistically comparable groups to make claims about the treatment of interest – in this case, the facilitated Design Challenges experience – it should be noted that the sample is biased toward science center visitors who self-select to participate in this type of engineering experience. The results of this study should not be generalized to all visitors to a science center, and obviously this study (purposefully) looked at a specific age range. However, as this self-selection bias exists in both the pre and post conditions, the inferential analyses employed are valid for exploring differences between groups once visitors make the decision to participate in the Design Challenges experience. Results from this research can, therefore, be generalized to other facilitated design experiences in science centers in which visitors decide for themselves to participate.

III. RESULTS AND DISCUSSION

This study set out to examine the effects of educator facilitation at drop-in engineering activities on participants' attitudes toward engineering and engineering self-efficacy. For each of these factors, this study considered how the impacts of facilitation may have differed between girls and boys and across the three different engineering activities (Bobsleds, Boats, and Claw). Results from both the quantitative and qualitative data are presented in the following section along with a discussion providing further interpretation of these findings. Research questions guiding the analyses were:

1. Do visitors' perceptions of engineering activities improve as a result of the facilitated Design Challenges experience?
2. What aspects of the interactions between museum educators and Design Challenges visitors contributed to changes in visitors' attitudes toward engineering and engineering self-efficacy?
    1. Does the number of interactions affect attitudes or self-efficacy?
    2. Does the point in process affect them?
    3. Does the content of interactions have an effect?
3. What are the primary motivations for on-going participation in the activity?
4. What other factors influence visitors' perceived success during the engineering process?

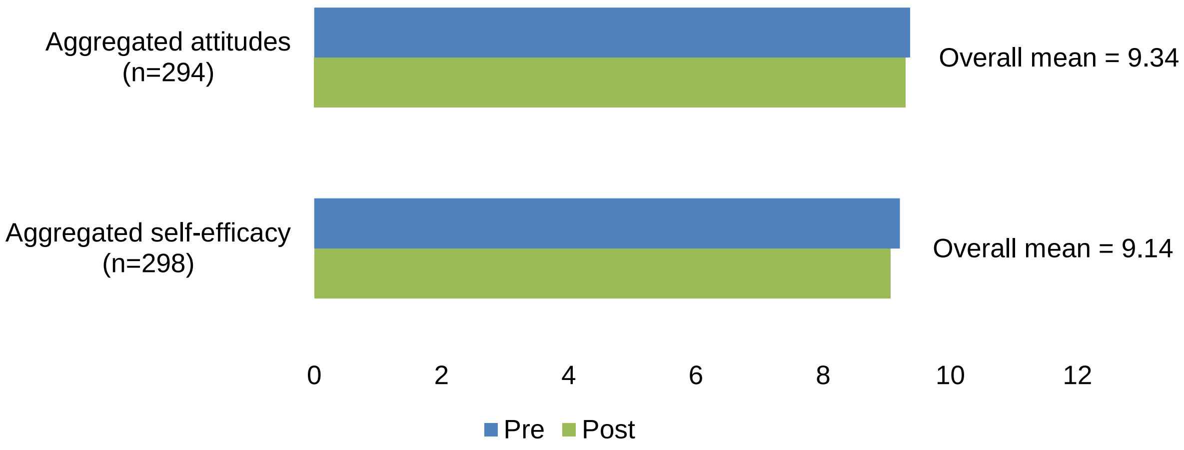
1. EFFECTS OF THE FACILITATED DESIGN CHALLENGES

This study included a comparison group of statistically similar children who were approaching but had not yet started participating in the Design Challenges experience. Both the pre group and the post group were given surveys including items related to attitudes toward engineering as well as engineering self-efficacy. The following section discusses the differences—or lack thereof—in engineering attitudes and engineering self-efficacy between the two groups to learn more about the effects of the facilitated Design Challenges experience.

1.1 Visitors who had not yet engaged in Design Challenges tended to give higher ratings on the item "I would like a job where I design and create things."

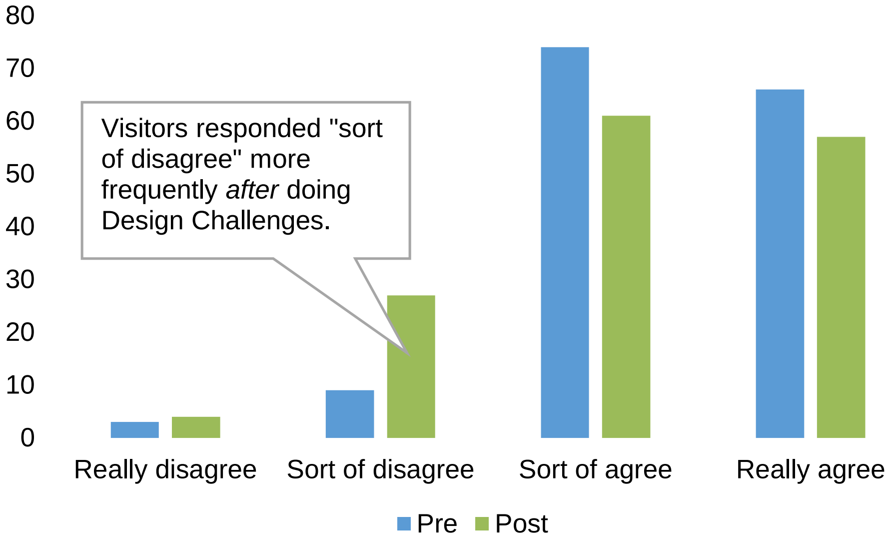
Visitors in both groups were asked to rate on a 4-point scale, where 1 was "Really disagree" and 4 was "Really agree," several items related to engineering attitudes, including future interest in engineering activities. As discussed in the Methods section, to create a more nuanced analysis, the three self-efficacy questions were summed to create a self-efficacy index score, and the four attitudes toward engineering items were summed to create an attitudinal index score. When aggregated, there were no differences in either attitudes or self-efficacy between visitors before doing a Design Challenges activity and after. This finding holds for both boy and girl subgroups.

Figure 10: Aggregated attitudes and self-efficacy, pre/post



In general, there were no statistically significant differences between the pre and post groups on individual items. However, there was one exception: on the item, "I would like a job where I design and create things," chi-square analysis showed that visitors who had yet to engage in Design Challenges tended to have higher ratings on this item than visitors who had just finished engaging in Design Challenges.

Figure 11: "I would like a job where I design and create things" (n=301)*



* Chi-square test: $\chi^2 = 11.02, p = .012$

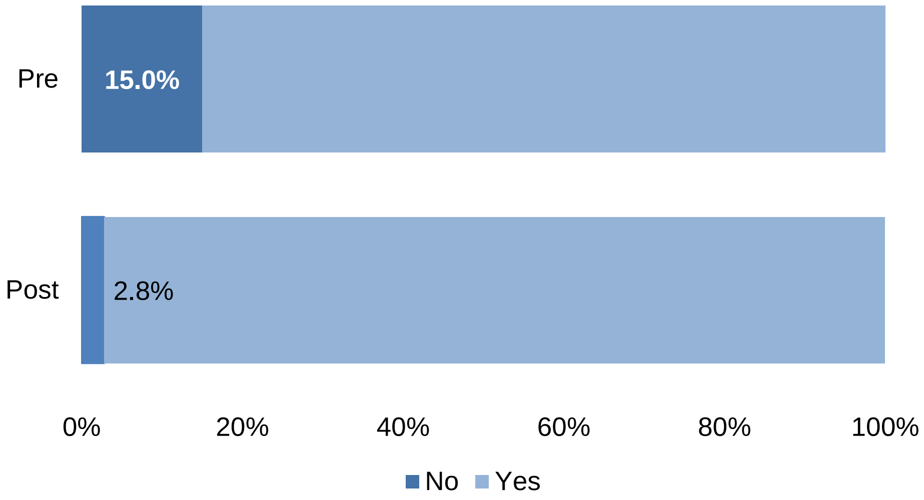
This difference was investigated further by examining the differences between girls and boys. When looking at girls only, there were no statistically meaningful difference between the pre and post groups. However, when looking at boys only, the statistically significant difference persisted ($\chi^2 = 8.386, p = .039$), indicating that boys' ratings on this question may very well be driving the differences seen for this item overall.

This difference is surprising, as it might be expected that visitors who participate in a hands-on engineering Design Challenges activity would have more interest in a job where they would get to design and create things, or at least not have less interest. Even though the treatment group rated themselves lower on this item, there were no statistically significant differences on the item just before this one on the survey, "I would like to be an engineer," between either boys or girls or across the whole sample, so the lower ratings should not be interpreted as saying that boys are less interested in engineering careers after doing the activities. One possibility is that the words "design and create" were less appealing to boys.

1.2 Visitors who had not yet engaged in Design Challenges were more likely to feel that they could not design, create, and test at home.

Children in both the pre and post groups were asked the following interview question: "Do you think you could design, create, and test a different (bobsled/boat/claw) by yourself if you had materials at home?" Overall results indicate that visitors who had not yet participated in Design Challenges were more likely to respond "No" to this question – and that visitors who had been through the facilitated activity almost exclusively said "Yes."

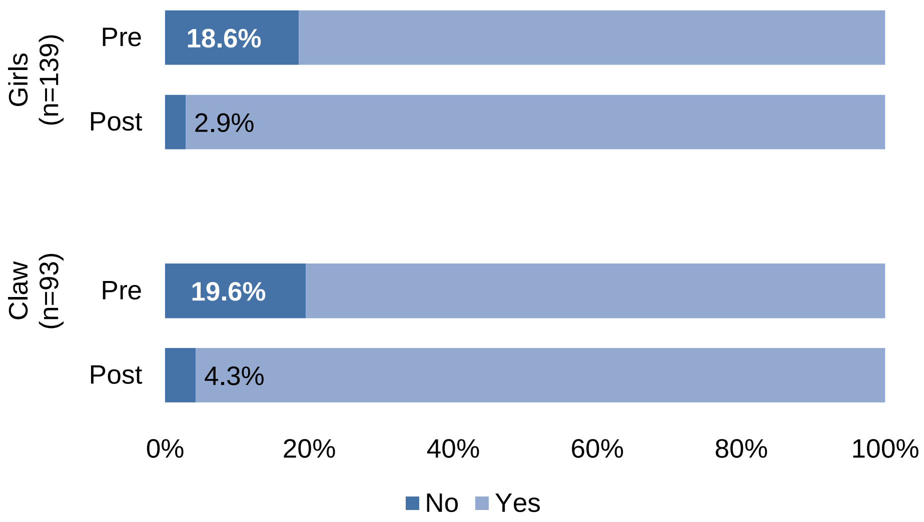
Figure 12: More subjects in the post group felt they could design, create, and test at home than in the pre group* (n=282)



* Chi-square test: $\chi^2 = 12.95, p < .001$

This was particularly true when analyzing girls and participants in the claw activity alone: differences between pre and post groups indicate that the experience of the facilitated Design Challenges activity significantly improved self-efficacy to do a similar design-based activity at home (see Figure 13, below).

Figure 13: Self-efficacy to design at home, girls and claw participants*



* Chi-square tests – girls subgroup: $\chi^2 = 8.87, p = .005$; claw subgroup: $\chi^2 = 5.23, p = .027$

This indicates that, although there were no changes from pre to post in the indexed survey items relating to self-efficacy, the effect of participating in a facilitated Design Challenges activity with skilled educators *does* impact individuals' self-efficacy when asked if they could do something similar at home.

2. EFFECTS OF VISITOR INTERACTIONS WITH EDUCATORS

Across all the post subjects, data collectors recorded over 1,000 interactions between educators and participants. Several aspects of these interactions were analyzed to determine their effect, if any, on engineering attitudes and self-efficacy; primarily, the number of educator-visitor interactions, the point in the engineering design process at which they occurred, and the content of the interactions. From this analysis, the following findings emerged:

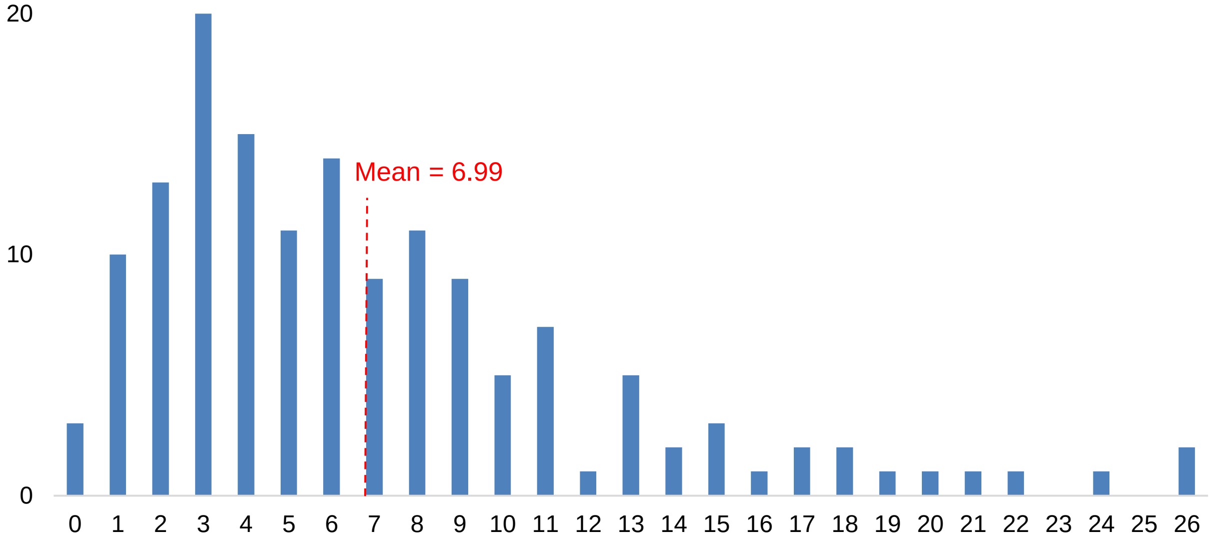
2.1 The number of interactions with an educator did not have an effect on participants' engineering attitudes or self-efficacy.
2.2 The point in the process at which an interaction occurred did not itself affect engineering attitudes or self-efficacy.
2.3 Participants who had an encouraging check-in with educators at any point during the activity were more likely to stay longer, iterate their designs more, and interact with educators more.

These findings are described in the following sections.

2.1 The number of interactions with an educator did not have an effect on participants' engineering attitudes or self-efficacy.

Design Challenges educators hypothesized that one aspect of the engineering activity that affects attitudes and/or self-efficacy could be the number of interactions participants have with an educator. Although number of interactions, number of iterations, and overall stay time are positively correlated[3], a long stay time does not guarantee a high level of facilitation, nor does it ensure a large number of interactions with educators. To investigate this, researchers first looked at the distribution of the number of interactions across the sample. As can be seen in the chart below, the most common number of interactions was three, and the mean number of interactions was just below seven.

Figure 14: The mean number of interactions among participants was approximately seven (n=150)



Based on this distribution, the number of interactions were split in multiple ways: above and below the mean point (two groups) and into three approximately equal groups for a low, medium, and high number of interactions, as defined by the data. The mean break point analysis compared participants with fewer than seven interactions (n=85) and those with seven or more (n=62). The low-medium-high analysis compared participants with three or fewer interactions (n=45), between four and eight interactions (n=59), and more than nine interactions (n=43).

When comparing ratings on engineering attitude and self-efficacy measures of participants with above- and below-average numbers of interactions, chi-square analysis showed no statistically significant differences. Similarly, when comparing ratings on the same items for participants between low and medium, medium and high, and low and high numbers of interactions, there were no statistically significant differences. This indicates that, although some individuals participating in a Design Challenges activity had no educator interactions after the activity

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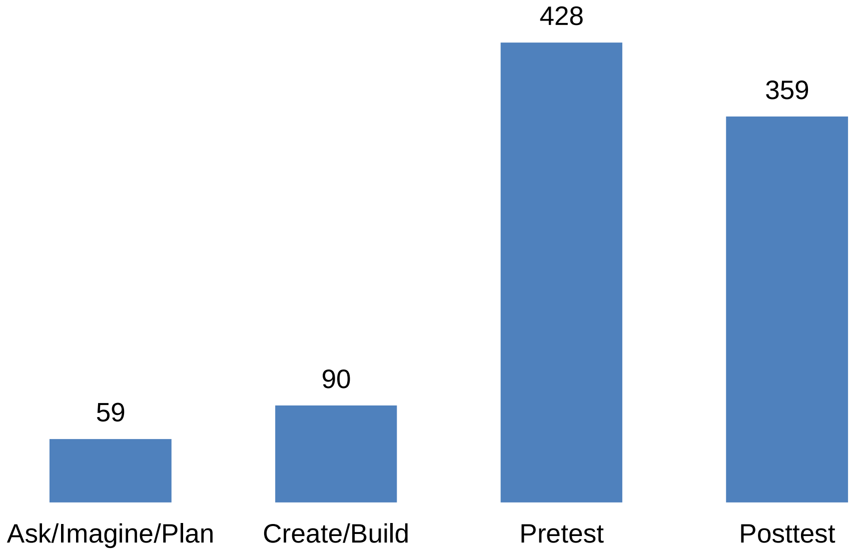
[3] Interactions / iterations: $r = .650$ ($p < .001$); interactions / stay time: $r = .689$ ($p < .001$); iterations / stay time: $r = .617$ ($p < .001$).

introduction, while others had over 20, the number of these interactions did not affect engineering attitudes or self-efficacy.

2.2 The point in the process at which an interaction occurred did not itself affect engineering attitudes or self-efficacy.

Across the many interactions that were observed, the majority of educator-visitor conversations occurred at the testing station, either just before or just after testing. This finding aligns with the program's educational approach and philosophy, given that Design Challenges educators report asking critical questions at this point in the design cycle to encourage visitors to think about how they can make changes to or improve their design.

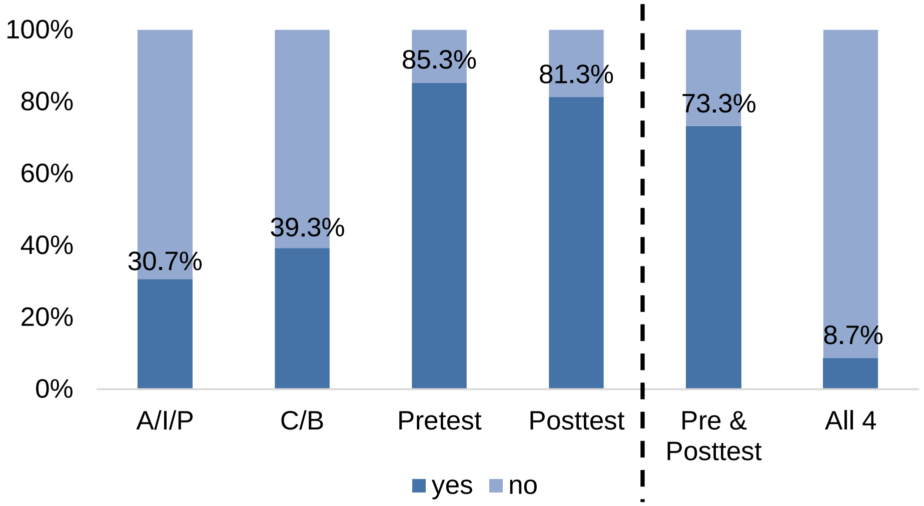
Figure 15: Phase of the engineering design cycle in which interactions occurred (n=936)



Note: Figure does not include interactions at boats-only sink/float station.

In fact, the majority of Design Challenges participants not only had an interaction with an educator during pretest (85.3%) or during posttest (81.3%), but almost three-quarters had an interaction during both of these phases of the design process. Just under 9% of participants were observed having educator interactions in each of the four phases of the design cycle (see Figure 16).

Figure 16: Proportion of visitors with at least one interaction during any design phase (n=150)



When these categories were compared – analyzing the group of individuals with an interaction during a particular phase against the group with no interaction during that phase – no differences were found in either aggregated measure of engineering attitudes or self-efficacy. Furthermore, a regression model was used to examine the impact of the number of interactions during each phase of the design process, accounting for participant age and gender; none of the variables accounting for interactions in a particular phase were found to have a significant impact on changes in either measure of attitude or self-efficacy.

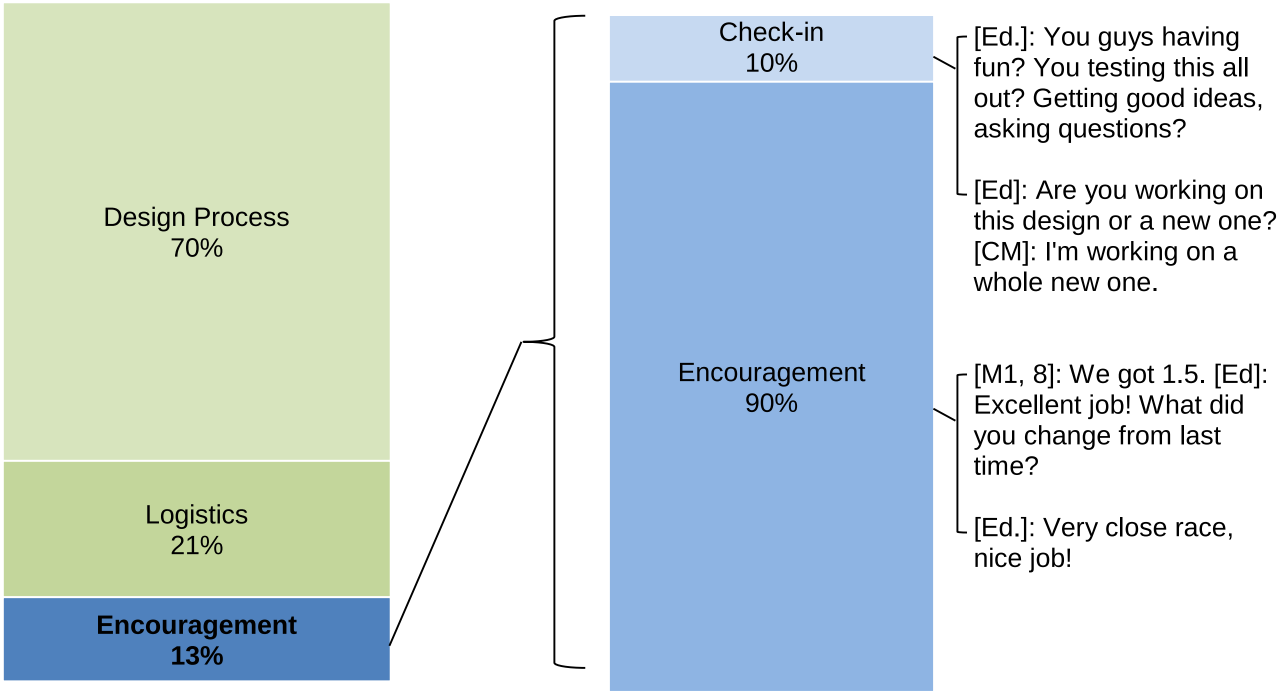
The results of these analyses suggest that it is not the point in the process in which the interaction occurs that has a significant impact on either engineering self-efficacy or attitudes.

2.3 Participants who had an encouraging check-in with educators at any point during the activity were more likely to stay longer, iterate their designs more, and interact with educators more.

As described in the Methods section, researchers recorded the content of each interaction (i.e. what was said) and during analysis coded the content into three broad categories: logistics, design process, and encouragement. Researchers looked at the three broad categories of interaction content to determine their effects in a variety of areas. In addition to looking at effects on engineering attitudes and self-efficacy, researchers also looked at effects of the type of interaction content on indicators of engagement, namely stay time, design iterations, and interactions with educators.

There were statistically significant differences when looking at the category of “encouragement,” which encompassed both simple encouraging phrases like “Nice job” or “Keep trying” and supportive check-ins such as, “How’s it going?” or “Did you test it yet?” Participants who had at least one encouraging check-in with an educator were significantly more likely to stay at the activity longer, test more designs, and interact with educators more. Specifically, visitors who had at least one encouraging check-in stayed 8 minutes longer, tested close to two additional designs, and had about four additional interactions with an educator, on average, than visitors who had no encouraging check-ins. The chart below summarizes what these interactions were like, and the table shows the exact differences.

Figure 17: Types of interactions visitors had with educators, not including unheard or irrelevant interactions (n=1049)



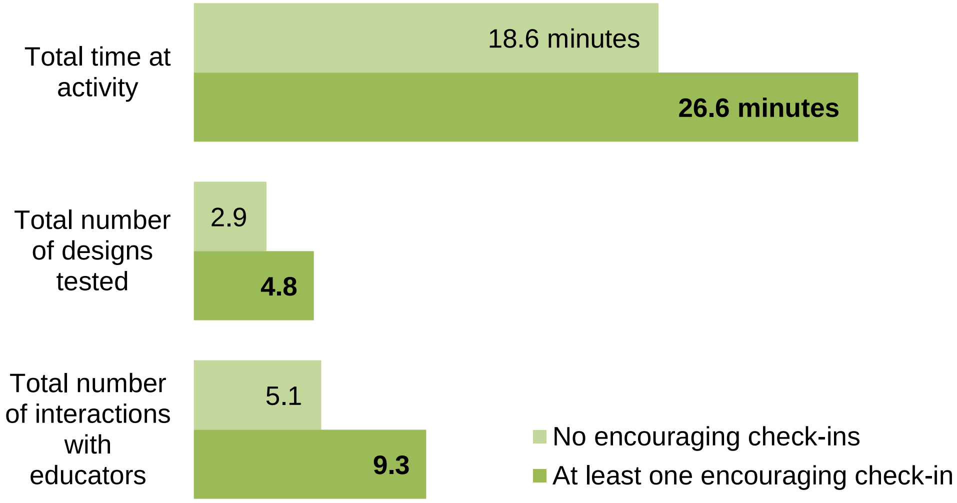
[Ed.]: You guys having fun? You testing this all out? Getting good ideas, asking questions?

[Ed]: Are you working on this design or a new one? [CM]: I'm working on a whole new one.

[M1, 8]: We got 1.5. [Ed]: Excellent job! What did you change from last time?

[Ed.]: Very close race, nice job!

Figure 18: Visitors with at least one encouraging check-in spent more time at the activity, tested more designs, and interacted with educators more (n=150)



*Mann-Whitney tests: U=1811, p<.001; U=1665, p<.001; U=1501, p<.001.

Furthermore, accounting for both gender and age, each additional interaction from an educator offering encouragement or simply checking in was found to significantly increase visitors' self-efficacy scores by one-half point across Design Challenges activities, which equates to almost ¼ of a standard deviation unit. In this analysis, gender and age were not significantly related to self-efficacy.[4] Testing these same factors against attitudinal measures, there was no effect of encouraging interactions on attitudes toward future participation in engineering.[5]

This result is particularly interesting as it provides additional support and context for a finding from an earlier, smaller study on educators' interactions at Design Challenges. This study showed that "visitors who were encouraged by the educators to try again completed significantly more build/test iterations than those who did not get this positive reinforcement" (Kollmann & Reich, 2007). Though the interaction coding was somewhat different between studies, both showed that some type of encouragement made a difference in aspects of visitor engagement.

2.4 A note on exclusions

For sections 2.2 and 2.3, several groups from the overall sample were excluded from analysis; specifically, this included three groups who engaged in the activity and tested their designs, but did not interact with any educators beyond the activity introduction. These groups clearly engaged in the activity, building and testing multiple iterations of their designs. Due to the nature of this analysis, however, a group with no interactions would necessarily be excluded from comparisons related to the type of content discussed or the point in the process when these conversations occurred. To include information about them despite their exclusion, these groups are described in more detail below.

Case 1, a 10-year-old boy, tested seven iterations of his bobsled. He stayed at the activity for 24.2 minutes, which was longer than the average total stay time across activities as well as the average stay time for the Bobsleds activity. Despite his relatively long stay time and high number of tests, the data collector did not observe him speaking with any educators. This boy indicated he had never participated in a Design Challenges activity before, and he visited with his mother, who indicated she had a low background in science and engineering.

During his interview, the participant mentioned interacting with an educator, so it is possible that he did speak with someone beyond the introduction. However, the data collector did not see or hear it, possibly due to a factor such as crowding, noise level, or another distraction. He said that he and the educator talked about "which materials went fastest," and that they "helped [him] decide the weight."

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[4] Multiple regression analysis was used to test the influence of encouragement on aggregated self-efficacy scores, accounting for variance explained by both age and gender of participants. Overall model results indicate that this set of variables was significantly predictive of self-efficacy ($F_{3,139}=3.306$, $p=.022$), although only weakly so (adj. $R^2=.046$). Although neither age nor gender were found to be statistically related to the outcome, ($t=-1.51$, $p=.135$; $t=-.633$, $p=.528$, respectively), encouragement was statistically significant ($t=2.688$, $p=.008$) in its relationship with self-efficacy ($\beta = .220$, $SE_{\beta} = .196$).

[5] Again, regression was used to analyze the aggregated attitudes measure, but overall model results were statistically non-significant ($F_{3,137}=.528$, $p=.664$).

Case 2, an 11-year-old girl, tested two iterations of her bobsled. She stayed at the activity for 8.4 minutes. She indicated no previous Design Challenges experience. While she tested twice, the educator manning the bobsled track did not speak at all during testing. However, this girl did listen to an unusually long introduction to the activity, at 2.4 minutes. The educator giving the introduction demonstrated the use of weight in the activity. Design Challenges was also particularly crowded on the day this girl visited, and only four educators were present, meaning that there was generally less opportunity for interaction and facilitation.

This girl mentioned the principles of using weight in her design during her interview. She described getting stuck because her bobsled was too slow, and said "I realized that if you put weight at the bottom it goes faster. It wasn't going fast before." Her mother mentioned the importance of educators in the interview, saying, "Without the interaction and enthusiasm [of the educators], I don't think she would have been as successful."

Case 3, an 11-year-old girl, tested one iteration of her bobsled. She had previously done the Boats challenge. She stayed at the Bobsleds activity for 5.4 minutes, and like Case 215, she had a relatively long introduction at 2.3 minutes. Also like Case 215, the activity was crowded, and only three educators were on hand.

In her interview, the girl described receiving design advice from the educators, such thinking about "how smooth something was" or "the effect of the weight on batteries." Her mother said that the educator was "good about explaining different materials."

3. PRIMARY MOTIVATIONS FOR ONGOING PARTICIPATION

Research question #3 addresses participants' motivations for persisting at the Design Challenges activity. Several interview questions were designed to inform this research question, including asking participants who tested more than one design why they decided to keep testing, and asking all participants whether or not they got stuck or confused, and if so, how they tried to solve the problem that was confusing them. Analysis of these questions led to the following findings:

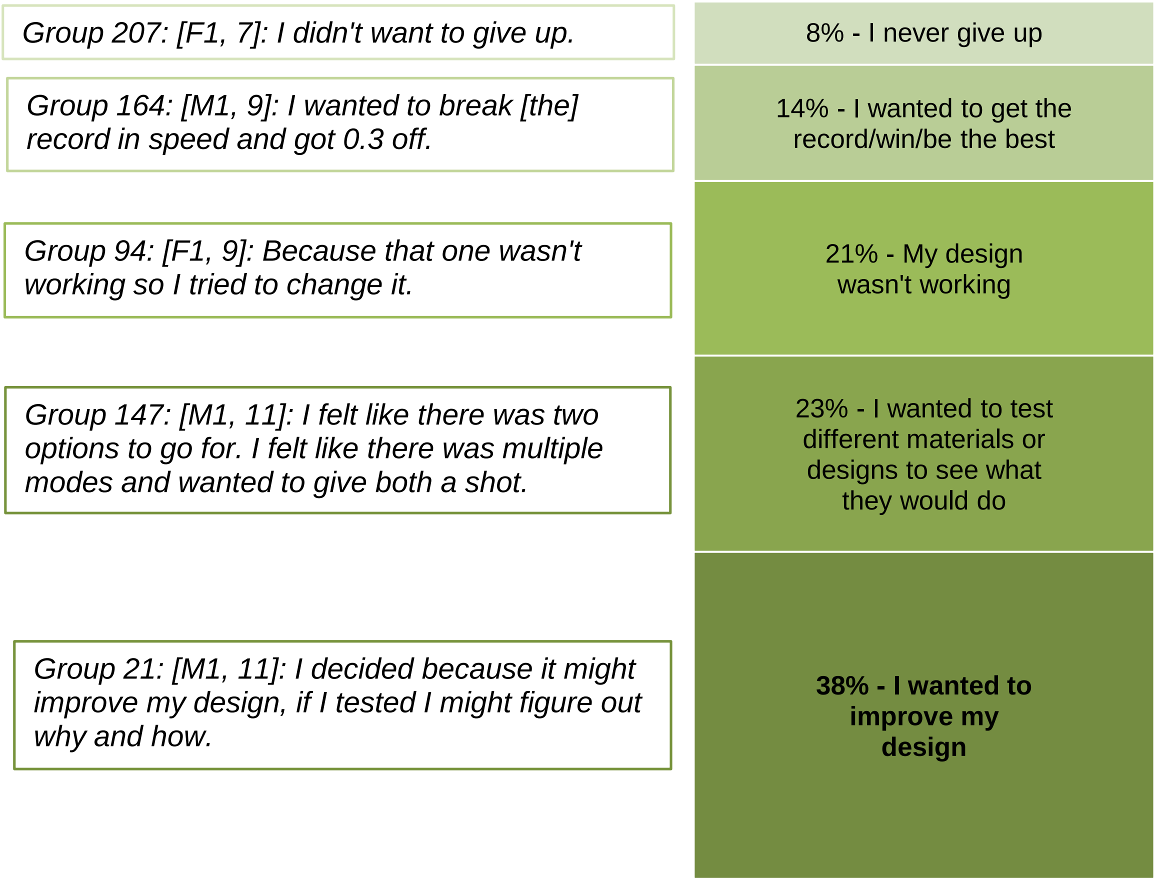
3.1 Visitors who tested more than one design were most often motivated by wanting to improve their designs.
3.2 Participants did not mention talking with educators to solve design problems, but about 40% said that the educators said something that helped them with their designs.

The findings are detailed in the next two sections.

3.1 Visitors who tested more than one design were most often motivated by wanting to improve their designs.

Of the total treatment sample of 150 participants, 115 (about 77%) tested more than one design. All of these participants were asked why they decided to keep testing. Participants gave five main reasons for persisting. The chart below shows the breakdown of reasons given for testing more than once from the 115 participants who did so.

Figure 18: “Why did you decide to keep testing?” (n=115)



Group 207: [F1, 7]: I didn't want to give up.

Group 164: [M1, 9]: I wanted to break [the] record in speed and got 0.3 off.

Group 94: [F1, 9]: Because that one wasn't working so I tried to change it.

Group 147: [M1, 11]: I felt like there was two options to go for. I felt like there was multiple modes and wanted to give both a shot.

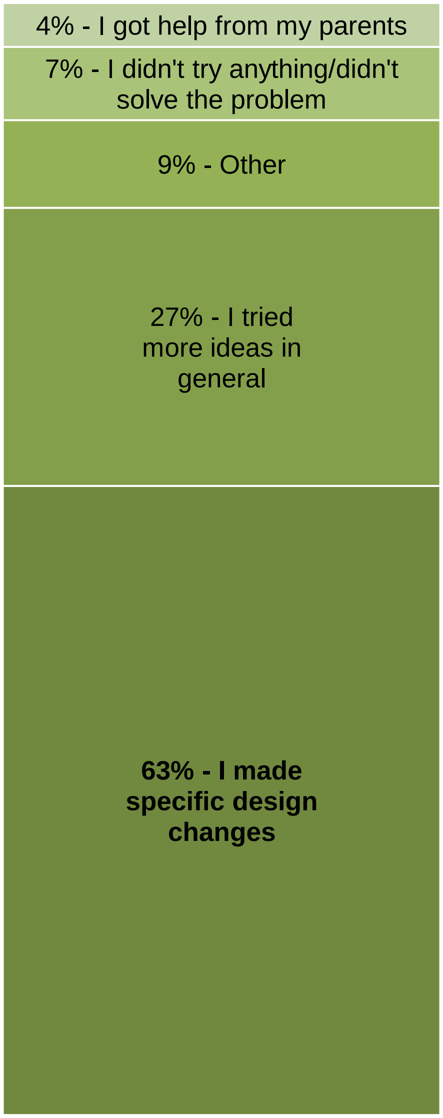
Group 21: [M1, 11]: I decided because it might improve my design, if I tested I might figure out why and how.

Comments that fell into the most frequently discussed category, “I wanted to improve my design,” were coded as such because they were framed in terms of personal improvement. This is distinct from the category of “My design wasn’t working,” in which the answer was framed in terms of the failure or shortcomings of the design. Of the participants who were motivated to continue testing to improve their design, 15 participants (34%) used the word “improve” or “improvement.” An additional 10 participants (23%) used the word or phrase “better” or “make it better.” The rest tended to refer to the particular Design Challenge activity (e.g. “make it faster” for the Bobsleds challenge or “carry more gems” for the Boats activity).

3.2 Participants did not mention talking with educators to solve design problems, but about 40% reported that educators said something that helped them with their designs.

Visitors were also asked if they got stuck or confused at all, and if so, what they did to try to solve the problem. When asked if they got stuck or confused, 67 of 150 participants (45%) reported that they did, and 83 of them (55%) said they did not. Similar to the way in which participants were motivated to persist in the activity by wanting to improve their design, most of them (63%) described the specific design steps they took to solve whatever problem was confusing them, sometimes in great detail. The chart below breaks down the problem-solving methods described by participants who said they got stuck.

Figure 19: "What did you do to try to solve the problem?" (n=67)



Group 187: [M1, 10]: Had him help me.

Group 97: [M1, 10]: I didn't.

Group 210: [F1, 9]: I don't exactly know.

Group 8: [M1, 10]: We tried to take that apart and think of ideas.

Group 188: [F1, 10]; You need something to scoop it and we saw the cups.

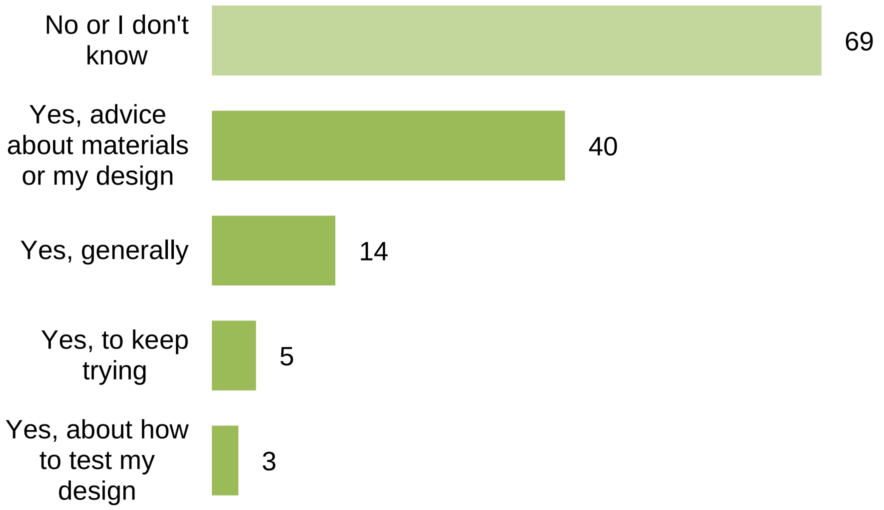
Group 3: [F1, 10]: I tried both of my ideas. I put a whole bunch of felt and stuff on it, then the other time I put in just one battery.

While few participants described getting help from their parents, no one specifically mentioned getting help from educators to solve their problems. However, this does not mean that facilitators were not helpful in assisting participants build their designs or solve problems. Participants were asked directly about their interactions with educators to understand more about visitors' perceptions of these interactions.

Participants were first asked if they had spoken with an educator or if one had spoken to them. About 86% (129 participants) said "Yes," that either they had talked to one or one had talked to them. This is notable by itself, because with rare exceptions, every participant interacts with an educator at least once due to the activity introduction; one might have expected everyone to say they had interacted with an educator. For example, in this study's sample, only one participant did not have the activity introduction (and that participant was observed having other interactions with educators). The 21 visitors who said they did not interact with an educator may have been too shy to answer the question or had a hard time remembering their experiences. They also may have not perceived those interactions with educators as a primary part of their Design Challenges experience.

The 129 participants were then asked what they talked with educators about, whether the educators said anything that helped with their design, and whether they said anything confusing. When asked if the educators said anything that helped with their design, 60 participants (40% of the total sample) said "Yes." The table below describes what the participants found helpful.

Figure 20: "Did [the educators] say anything that helped you with your design?" (n=129)



While 40% of the sample said that educators said something that helped with their design, that also means that the remaining 60% either did not feel the educators said anything that helped with their design or did not feel that they had talked to educators much at all. This is by no means a negative reflection on educators, and in fact is consistent with part of the Design Challenges philosophy, which is to allow for independent exploration and problem-solving rather than relying on explicit instruction or direction from facilitators. Combined with Finding 3.1 about motivations for ongoing persistence, it seems that participants in the Design Challenges activities are mostly intrinsically motivated to improve their designs.

4. OTHER FACTORS INFLUENCING PERCEPTIONS OF SUCCESS

Researchers were also curious about other factors that might have affected participants' perceptions of success, as well as parent perceptions of their child's success. Several questions on the adult interviews and the child interviews for the pre and post groups addressed this research question. After analysis, the following findings emerged:

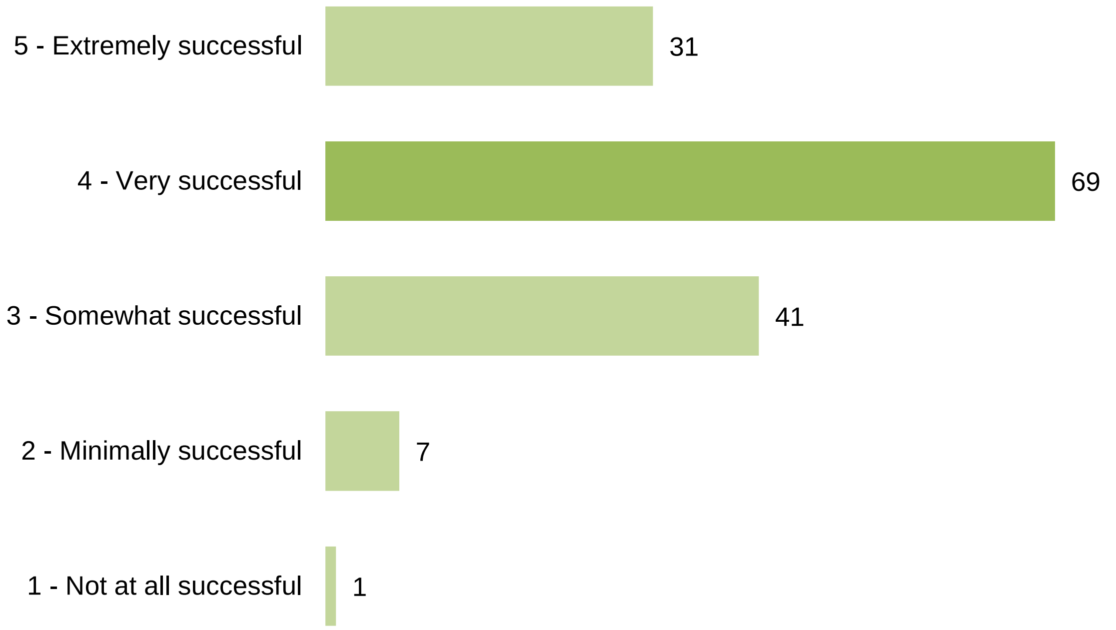
4.1 Parents tended to rate their children’s success highly but with room for improvement, and based their ratings on perceptions of the child’s participation in the engineering design process.
4.2 Participants also tended to rate their own success highly but with room for improvement, and usually based this judgment of future success on their prior experiences.

These findings are discussed below.

4.1 Parents tended to rate their children’s success highly but with room for improvement, and based their ratings on perceptions of the child’s participation in the engineering design process.

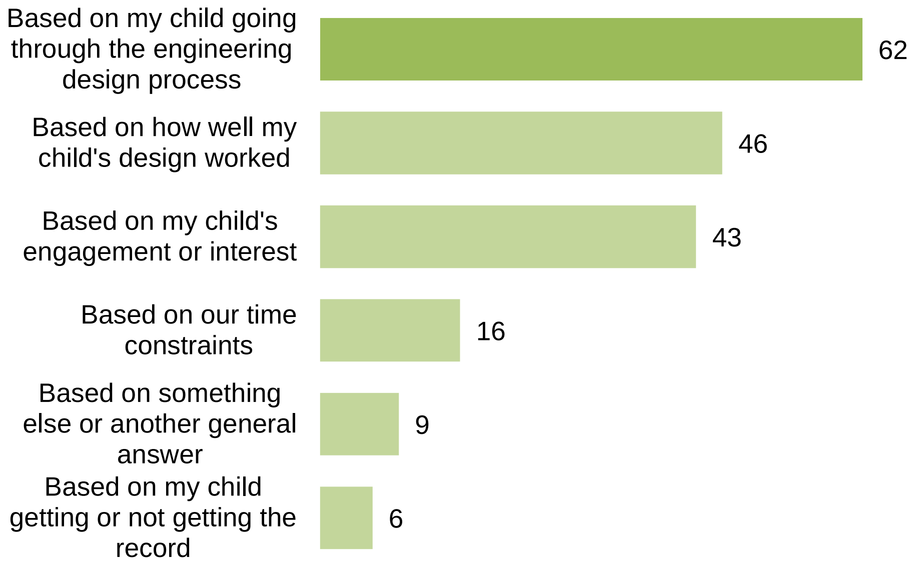
Parents of post subjects were asked to rate their child’s success in the Design Challenges activity on a 5-point scale, where 1 was “Not at all successful” and 5 was “Extremely successful.” Parents were asked to consider success in relation to the objective of the day’s Design Challenge activity, whatever they perceived that to be. Parents most commonly rated their child’s success as a 4 out of 5—high, but with room for improvement.

Figure 21: “How successful do you think your child was in relation to the objective of today’s activity?” (n=150)



Parents tended to base these ratings (whether low or high) on whether or not they felt their child engaged in the engineering design process. For example, one mom (Group 12) said of her child, “He kept at it. He wanted to improve the design. He wasn't satisfied with just one iteration.” Similarly, one dad (Group 204) said “[He] started to understand how the changes were effective, but didn't quite get it.” The Design Challenges staff aim to emphasize process over product in their activities, and this message seems to have transferred to parents' thinking about their children's success as well. About 41% of parents (62 people) used this reasoning. Other explanations parents gave for their ratings included the success of the design itself, their child's interest, and their time constraints at the activity.

Figure 22: "Why did you select that rating?" (n=150)

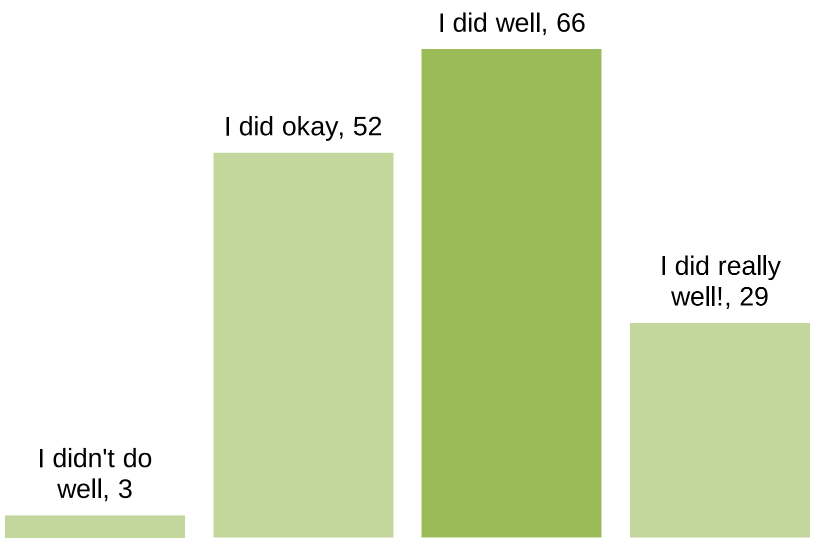


There did not appear to be major differences in the reasoning for parents of girls and parents of boys, though slightly more parents of girls based their ratings of success on engagement in the engineering design process while slightly more parents of boys based their ratings of success on the strength of their child's design or their child's interest or engagement in the activity.

4.2 Participants also tended to rate their success highly but with room for improvement, and usually based this judgment of future success on their prior experiences

Similar to their parents, children tended to rate their success highly but with room for improvement. The post group rated their success as part of the survey instrument. Most often, participants rated themselves a 3 out of 4, meaning "I did well." This responses was selected by 66 participants, or about 44% of the total sample.

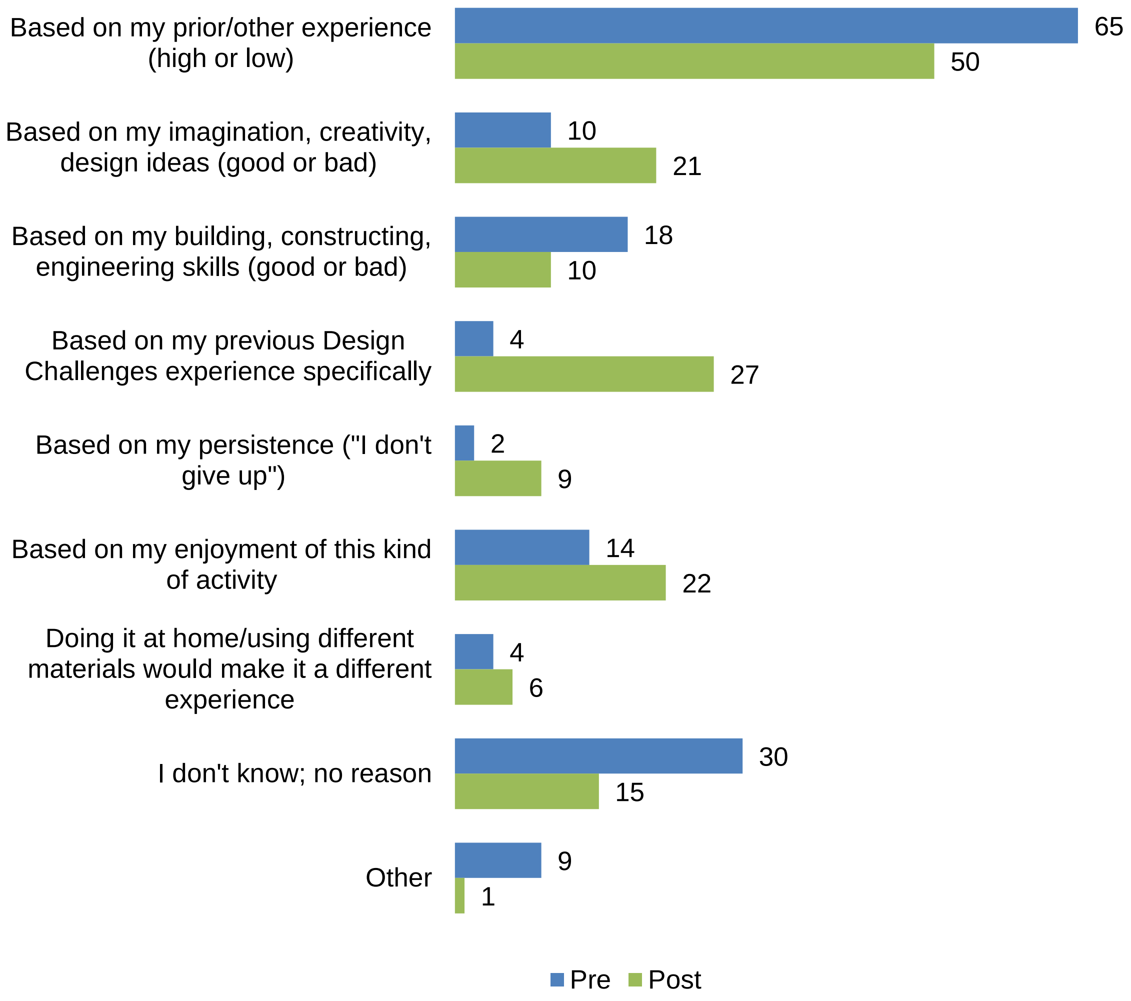
Figure 23: "How well do you think you did at the Design Challenges activity today?" (n=150)



Unlike the adults, the child participants were not asked why they selected that rating. However, the child interview did include a related question about whether the respondent felt they could design, build, and test a different kind of bobsled, boat, or claw if they had the materials at home. Respondents were then asked how good they felt they were at designing and building things and why. This set of questions was asked of both the pre and post groups.

When answering, most visitors (52% of both the pre and post groups) said they were "Good," "Pretty good," "Very good," "Really good" (or some variation on "Good") at designing and building things and based their reasoning mostly on their prior experience. Other reasons included creativity, skill, persistence, and enjoyment.

Figure 24: Individuals' reasons for stating they are good or not good at designing & building (n=150)



While a small number of participants in the pre group based their assessment of designing and building aptitude on their previous Design Challenges experience, this response was much more common among the post group, having just completed the Design Challenges activity. This suggests that engaging in facilitated Design Challenges experiences provides a basis for children to think about their success in future engineering activities.

IV. CONCLUSION

This study provides a number of interesting insights for researchers and museum educators alike. The fact that encouraging check-ins with educators was significantly related to increased indicators of engagement (i.e., stay time, design iterations, overall number of interactions) provides additional support and context for a finding from a previous study on educator interactions at a design-based activity. Kollmann and Reich (2007) found that “visitors who were encouraged by the educators to try again completed significantly more build/test iterations than those who did not get this positive reinforcement” (p. 26). This new finding also highlights the importance of encouragement to other museum educators who facilitate similar design-based activities. The type of encouragement that was associated with higher engagement was often simple, such as “Nice job!”, “That looks cool,” or “That’s the spirit, keep trying.” New educators, whether staff, interns, or volunteers, can be trained to encourage and check in with visitors, and many educators may provide this type of encouragement naturally. This type of facilitation requires no specialized content knowledge around engineering design, but being a positive presence through encouragement and supportive check-ins can make a difference in visitor engagement.

Many findings also provide support for Design Challenges’ educational philosophy. For instance, Design Challenges staff frequently emphasize “process over product”; in other words, the visitor’s engagement in the engineering design process (testing and improving their design) is more important than how well the design itself works or whether or not the visitor makes the record board. As described in finding 4.1, when asked about their children’s success in the activity, most parents also based their ratings of their child’s success on the extent to which they felt their child had engaged in this process. While it is possible that many parents enter the activity also valuing process over product, an additional possibility is that Design Challenges staff are effectively communicating this philosophy to parents during the activity.

These rich data provide many possibilities for future analysis, beyond just the topics addressed by the research questions. For instance, though researchers looked at the effects of several aspects of facilitation to address the research questions, existing data could be used to further investigate these aspects in combination. Although analyses showed that the point in the engineering design process at which an interaction occurred did not in and of itself make a difference, additional analyses could focus on the effects of encouragement in the post-test phase alone, design feedback alone in the ask/imagine/plan phase, or any other combination that was of interest.

This study also raises additional questions that could be addressed in future studies. For instance, observations in this study focused only on Museum educators’ interactions with visitors, but parents also provide facilitation and support to their children during the activity. Future research could investigate the content and effects of parent facilitation encouragement in more detail than in previous studies, or look specifically at the effects of parent encouragement on engineering attitudes, self-efficacy, or activity engagement. It is also possible that there occurs a point at which encouragement has less of an effect on visitors or at which visitors perceive the encouragement as “empty,” and new data may be able to indicate this point of diminishing returns.

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APPENDIX A: OBSERVATION INSTRUMENT

Focus Child: ☐ Boy ☐ Girl **Crowding level:** ☐ Low ☐ Fluctuating ☐ High
Lead educator: ☐ Lydia ☐ Tricia ☐ Adrian ☐ Becky **Total # of educators:** _______
Intro Spiel: ☐ Activity goals ☐ Rules ☐ Record board ☐ Magnet/clean-up ☐ Asks simple ques.
TIME: ______ ☐ Materials ☐ "Engineer" ☐ Connects to prior experience
Wrap-up: ☐ Clean-up ☐ Magnet

Interaction # _________ **Time started:** __________ **Time ended:** __________

Timing: ☐ During Ask/Imagine/Plan phase
☐ During Create/Build phase
☐ Pre-Test ☐ (Boats) Sail/float-test
☐ Post-Test

Initiated by: ☐ Child ☐ Educator ☐ Parent ☐ Other group member

Iteration # __________

Conversation:

Interaction # _________ **Time started:** __________ **Time ended:** __________

Timing: ☐ During Ask/Imagine/Plan phase
☐ During Create/Build phase
☐ Pre-Test ☐ (Boats) Sail/float-test
☐ Post-Test

Initiated by: ☐ Child ☐ Educator ☐ Parent ☐ Other group member

Iteration # __________

Conversation:

[Interaction boxes repeated as necessary]

Other notes:

Number of designs tested: ______________________

Total time at activity: _________

APPENDIX B: POST INTERVIEW AND SURVEY, CHILD

1. [If the child tested more than 1 iteration]: We saw you test more than one design. Why did you decide to keep testing?

2. a. Did you get stuck or confused at all during the activity? If so, tell me about that time.

    b. [Follow-up] What did you do to try to solve the problem?

3. a. Did you talk with any of our staff members today? Yes No
    [If no, probe:] Did they talk to you at any point? Yes No
    b. Tell me about one of the times you talked to them. What did you talk about?

    c. Did they say anything that helped you with your design? If so, what was that?

    d. Did they say anything that was confusing or not helpful? If so, what was that?

4. a. Do you think that you could design, create, and test a different kind of [bobsled/claw/boat] by yourself if you had materials at home? Yes No
    b. [Follow-up]: How good do you think you are at designing and building things? (If child seems stuck, prompt: Would you say you're Really Good, Pretty Good, Okay, or Not-So-Good?)

    c. Why do you say [repeat the word child uses]?

5. a. Before today, had you ever participated in a Design Challenges activity here at the Museum?
Yes No
[If yes]:
    b. Have you done the **bobsled** challenge? Yes No
    c. Have you done the **arcade claw** challenge? Yes No
    d. Have you done the **boat** challenge? Yes No

1. What did you think of the Design Challenges activity you did today? (Circle <u>one</u> only.)			
No fun at all ☹	**A little fun…**	**A <u>lot</u> of fun**	**TONS OF FUN! ☺**
2. How well do you think you did at the Design Challenges activity today?			
I didn't do well ☹	**I did okay**	**I did well**	**I did really well! ☺**

3. Please tell us how much you agree or disagree with each statement. (Circle <u>one</u> each.)

a. I would like to be an engineer.			
Really disagree	Sort of disagree	Sort of agree	Really agree
b. I would like a job where I design and create things.			
Really disagree	Sort of disagree	Sort of agree	Really agree
c. I would like to do this design activity again.			
Really disagree	Sort of disagree	Sort of agree	Really agree
d. I would like to do another design activity.			
Really disagree	Sort of disagree	Sort of agree	Really agree
e. I can build a mini-bobsled that can race on a track.			
Really disagree	Sort of disagree	Sort of agree	Really agree
f. I can build a mini-arcade claw that picks up toys.			
Really disagree	Sort of disagree	Sort of agree	Really agree
g. I can build a mini-boat that sails on water.			
Really disagree	Sort of disagree	Sort of agree	Really agree

4. **How old are you?** ____________ years old

APPENDIX C: POST INTERVIEW AND SURVEY, ADULT

1. Thinking about your child's experience in today's activity, how successful do you think he/she was *in relation to the objective of the activity* - on a scale of 1 to 5, with 1 being "not at all successful" and 5 being "extremely successful"?

   1 – Not at all successful
   2 – Minimally successful
   3 – Somewhat successful
   4 – Very successful
   5 – Extremely successful

   b. [Follow up:] Why did you select that rating?

2. Did you notice your child interacting with a Museum educator during the activity? **Yes** **No**
   b. How did these interactions impact your child's interest in the activity, if at all?

   c. And how did these interactions impact your child's success in the activity, if at all?

3. Did you take a hands-on approach to the activity? [NOTE: should be visible from observation – prompt with comments about observed behavior.] **Yes** **No**
   a. Why did you decide to participate in this way?

   b. Did the Museum educator's interaction with your child influence your decision to participate in this way?

4. Would you characterize your level of background in science or engineering as low, medium, or high?
   ☐ Low ☐ Medium ☐ High
   b. (If medium/high) Do you have a degree or career in either science or engineering?

1. Indicate your responses to each of the following statements in reference to your <u>knowledge</u> of engineering using the provided scales.

1 = I do not know.
2 = I have a vague understanding, but am not confident in my knowledge.
3 = I have some understanding, but not enough to explain it to my child.
4 = I have enough understanding to explain it to my child, but I am not confident enough to teach others.
5 = I am confident enough in my understanding to explain it to others.

		1	**2**	**3**	**4**	**5**
a.	I know what engineers do.	☐	☐	☐	☐	☐
b.	I know how engineering can be used to help society.	☐	☐	☐	☐	☐
c.	I know how engineering is different from science.	☐	☐	☐	☐	☐

2. Indicate your responses to each of the following statements in reference to levels of <u>interest</u> using the provided scales.

a. How would you rate <u>your child's</u> interest in **science** on a scale of 0 to 10?

No Interest **Extreme Interest**
0 1 2 3 4 5 6 7 8 9 10

b. How would you rate <u>your child's</u> interest in **engineering** on a scale of 0 to 10?

No Interest **Extreme Interest**
0 1 2 3 4 5 6 7 8 9 10

c. How would you rate <u>your</u> interest in **science** on a scale of 0 to 10?

No Interest **Extreme Interest**
0 1 2 3 4 5 6 7 8 9 10

d. How would you rate <u>your</u> interest in **engineering** on a scale of 0 to 10?

No Interest **Extreme Interest**
0 1 2 3 4 5 6 7 8 9 10

3. Do you homeschool your children?

☐ Yes →
☐ No

If yes, are you using the museum today for homeschool activities?

☐ Yes
☐ No, but we have in the past
☐ No, we don't use the museum for homeschooling needs

That's the end of the survey!

APPENDIX D: PRE INTERVIEW AND SURVEY, CHILD

1. a. Why did you decide to come to the Design Challenges activity today?

   b. What kinds of things are you hoping to do at the Design Challenges activity today?

2. a. Do you think that you could design, create, and test a [bobsled/claw/boat] by yourself if you had materials at home? Yes No

   d. [Follow-up]: How good do you think you are at designing and building things?

   e. Why do you say [repeat the word child uses]?

   f. How much do you like designing and building things?

   g. Why do you say [repeat the word child uses]?

3. a. Before today, had you ever participated in a Design Challenges activity here at the Museum?
Yes No

[If yes]:

f. Have you done the **bobsled** challenge?	Yes	No
g. Have you done the **arcade claw** challenge?	Yes	No
h. Have you done the **boat** challenge?	Yes	No

1. How excited are you to do today's Design Challenges activity? (Circle one only.)

Not excited at all ☹	**A little excited…**	**Very excited**	**SUPER EXCITED! ☺**

2. Please tell us how much you agree or disagree with each statement. (Circle one each.)

a.	**I would like to be an engineer.**			
	Really disagree	Sort of disagree	Sort of agree	Really agree
b.	**I would like a job where I design and create things.**			
	Really disagree	Sort of disagree	Sort of agree	Really agree
c.	**I can build a mini-bobsled that can race on a track.**			
	Really disagree	Sort of disagree	Sort of agree	Really agree
d.	**I can build a mini-arcade claw that picks up toys.**			
	Really disagree	Sort of disagree	Sort of agree	Really agree
e.	**I can build a mini-boat that sails on water.**			
	Really disagree	Sort of disagree	Sort of agree	Really agree

3. **How old are you?** ____________ years old

APPENDIX E: OUTLIERS

Although they were excluded from analysis, the two outliers in the overall sample still provide valuable insight into how highly engaged children interact with educators and take part in the Design Challenges activity. The two outliers were one boy and one girl, and both stayed at the activity for over an hour. The boy was 10 years old, built 20 iterations of his boat design, and stayed at the activity for 86.2 minutes. The girl was 9 years old, built 32 iterations of her bobsled design, and stayed for 61.2 minutes.

Both children said they had done a Design Challenges activity before. The girl had done the bobsleds activity another time, and the boy had done both the boats and claw activities. On her survey, the girl rated herself a 1—the lowest end of the scale—on the two self-efficacy items related to the two Design Challenges she had not done before (Boats and Claw), and a 3 on building a bobsleds, which she had just done. The boy rated himself a 4—the highest rating—on building a boat, which he had just done, a 2 on building a claw, and a 3 for building a bobsled, which he had not done.

Interestingly, neither child perceived themselves as being maximally successful at the activity. Like most participants, they both rated themselves a 3 out of 4 when asked on the survey how well they thought they did at the activity. At several points in the interview, the boy even referenced being confused or frustrated. For instance, when asked why he kept testing, he said, “To try and improve my time. Some kept getting worse. I observed other boats to see what they did.” When asked if he got stuck or confused, he said, “Yeah. I was confused when I tried one differently, when one design was a little different but the time would be completely different.” Then when asked why he said he was just “okay” at designing and building things, he explained, “I don't know. I tried a bunch of stuff, didn't really work. It was hard to get the best, and that gets frustrating.”

The girl assessed herself as being “pretty good” at designing and building things and also based her answer on her Design Challenges experience, saying, “I didn't get the [current] record, but I got the record [before], and someone broke it.” She described encountering less frustration than the boy, but when asked if she got stuck or confused, she said, “Not really,” but also acknowledged that “sometimes the batteries, the weight made it slower.”

Both parents accompanying the children were their fathers, and like most adults, they rated their children’s success as a “4” on the 5-point scale. Both also based these ratings on their child’s engagement in the engineering design process, saying:

- [AM, boy’s father]: “I think if he observed other—well, he did observe others who were winning…but when he saw his design slowing he could have changed other things. But he loved it, stuck to it.”
- [AM, girl’s father]: “She started to understand what changes needed to be made to make it faster or slower.”

Overall, it is interesting to note that even though these two children were extremely engaged in terms of stay time and design iterations, they still experienced struggle and even frustration, and both the children and their parents perceived that there was room for improvement.