Engineering Awareness at Design Challenge Exhibits
(Fundamental)

Introduction

Engineering in communities

An increasing number of federally funded projects have focused on encouraging youth and families to exercise engineering skills (e.g., GRADIENT [1], Engineering is Elementary [2], and Head Start on Engineering [3]). This trend, paired with the increasing popularity of design challenge-based engineering learning experiences at science centers [4], illustrates the potential of engineering education outside of the classroom. Informal environments, such as science centers, are advantageous venues to engage the public with activities that present engineering as social, altruistic, relevant and compelling, without the time and performance pressures often present in formal settings [5], [6], [7]. In creating a designed educational environment, exhibit developers are in a unique position to influence the way visitors think, feel and talk about engineering. Furthermore, staff working on the floor of the museum can help youth and families while they are at an exhibit, gain skills and knowledge about the engineering we do, or can do, for everyday and local challenges. As part of the National Science Foundation (NSF)-funded Designing Our Tomorrow (DOT) project, which is concerned with helping youth and families build capacity to address challenges in their communities, researchers designed this exploratory study of fundamental relationships to better understand how to foster awareness of engineering in learners—that is, to help learners recognize strategies and skills they use when going through a problem-solving process as part of the process of engineering.

The term engineering is often used to refer to the field of work, or the profession of an engineer. However, engineering is also the term for the systematic process of identifying and solving problems through an iterative series of steps. This last definition focuses on the iterative and problem-solving aspects of engineering as a process, and is the definition used in this paper. This research values engineering broadly, as an approach to problem-solving that includes not only the work of professional engineers, but also strategies and skills that people use, or could use, to address challenges in their own lives and in their communities. By valuing engineering in this way, educators and learners can participate in dialogue about how engineering appears in their lives and their personal actions.

Although steps in the engineering process are, for most people, part of their everyday lives and community activities, it is not clear whether visitors recognise or acknowledge that the steps and processes they use as they define problems, and develop, test and refine solutions, are part of engineering. In order for people to work together on community priorities that involve engineering, it is beneficial for them to recognize that they are doing engineering, so they can collectively coordinate their activities. This recognition, or awareness that engineering is a process that everyone can do, allows them to realize that engineering is relevant, accessible and inclusive.

To benefit the researchers and practitioners working to improve engineering activities in museums, this study explored how groups engaging in design challenge activities at exhibits describe and characterize what they are doing, and the extent to which they report that the practices and strategies they are exercising are part of a problem-solving process or even an engineering process. This paper describes instruments used to capture facets of engineering awareness, and discusses how this approach can contribute to conversations in the field on relationships between facets of engineering awareness, and possible next steps in design and development research.

Engineering and Awareness

Museum researchers and developers generally apply a sociocultural perspective to learning and education [7]. With this perspective, the skills and practices associated with engineering are social problem-solving processes taking place within groups. This perspective suggests that learning occurs as social groups develop language, strategies, shared values, and norms of participation through everyday interactions with each other and the world around them. In this way, knowledge and skills are socially co-constructed to form a commonly understood notion of something like engineering processes. In addition to the sociocultural perspective, education researchers, practitioners and educators have used various frameworks to describe facets of knowledge, including awareness, that they might observe or try to elicit. One of these frameworks is Bloom's Taxonomy, a framework that was updated to *A taxonomy for learning, teaching, and assessing: A revision of Bloom's Taxonomy of Educational Objectives* in 2001 [8]. Bloom's Taxonomy complements the sociocultural perspective when trying to understand facets of commonly understood constructs.

In this study, researchers and educators are interested in facets of the awareness of doing engineering. The sociocultural perspective suggests that awareness of a common construct like engineering can be formed by individuals through many different learnings gathered at different times. In that way, awareness of the construct of engineering should not be measured directly, but rather, multiple meaningful facets should be measured to allow for and capture a diversity of learnings that might contribute to awareness and understanding of doing engineering. Knowing how to use or apply the practices of engineering, can be separate from knowing that one is using those practices. The NSF *Framework for Evaluating Impacts of Informal Science Education Projects* [9] distinguishes between doing (procedural knowledge) and understanding (factual knowledge): the authors provide examples in which visitors can display a skill (e.g. supporting a claim) without recognizing that they were doing so. These two ways of knowing are captured in different impact categories within the framework: the Skills category includes the procedural aspects of knowing, while the Knowledge category includes declarative aspects of knowing. This is consistent with Krathwohl's four categories of knowledge from the revision of Bloom's taxonomy [10] which include (1) factual knowledge, (2) conceptual knowledge, (3) procedural knowledge, and (4) metacognitive knowledge.

In this study, awareness is accepted as a form of knowledge, and engineering awareness specifically as recognition within a social group that certain practices and processes are associated with engineering as a problem-solving process. Described in Krathwohl's taxonomy [10], engineering awareness is comprised of metacognitive knowledge that connects procedural knowledge (the ability to engage in engineering practices) to factual and conceptual knowledge (knowing what those practices are, knowing that they are part of a problem-solving process), and ultimately knowing that these practices and processes are associated with the socially constructed term *engineering* (Figure 1). In other words, in this study, engineering awareness is recognizing that one uses a set of practices and strategies, that the practices are part of a problem-solving process, and that the practices, strategies, and process are part of doing engineering.

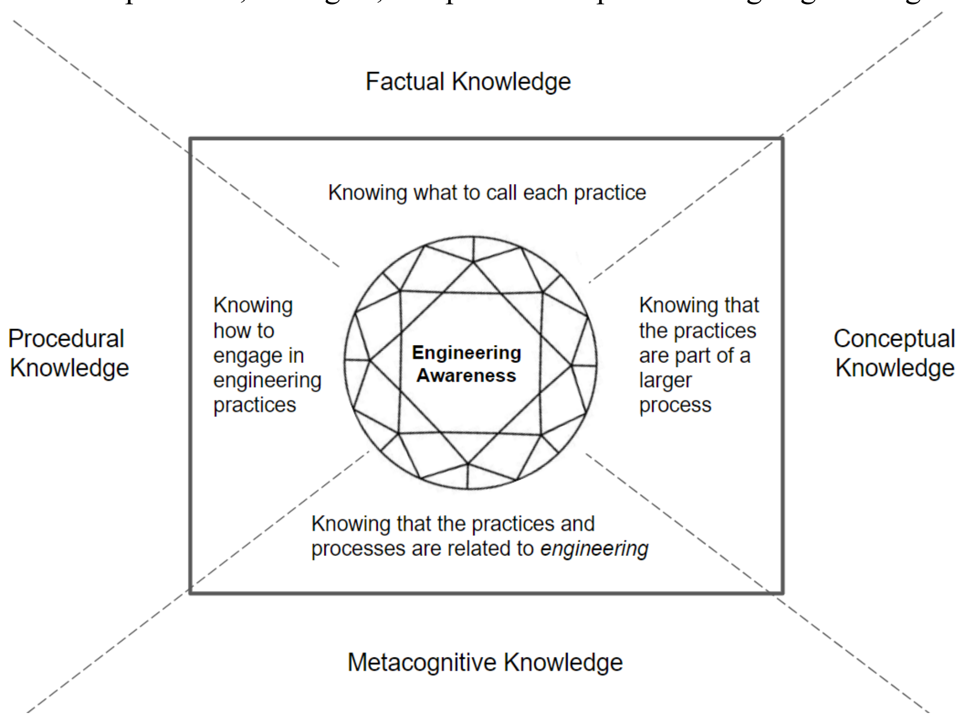

Figure 1: Diagram of contributions of different forms of knowledge to Engineering Awareness. Adapted from Jideani and Jideani [11].

This research explored the premise that exhibits, as educational experiences, can contribute to visitors' awareness that they are exercising engineering design practices. The efforts of educators to foster awareness of engineering in the general public are intended to support capacity-building in communities by helping youth and families recognize that their actions are a part of engineering, and that engineering is an approach to solving problems in their own lives and communities. The educators and researchers of DOT understand that the educational environment they design and the research techniques they use will influence the self-report of participants. Therefore, this exploratory study is structured to understand how the design of educational experiences and research techniques might elicit different responses from participants so that these experiences and techniques can be improved to promote awareness of engineering through future research in design and development.

Research Questions

Researchers' objective was to measure facets of engineering awareness through learners' associations with engineering design practices—the fundamental steps involved in the process of engineering. These practices include: defining a goal, making a plan, building and testing designs, making improvements, and assessing completion. In this study, facets of engineering awareness of learners were determined by examining their ability to identify engineering-related practices, strategies, and processes they used; and associating those practices, strategies, and processes with the construct of engineering.

To conduct this exploration, researchers implemented three approaches to measure facets of engineering awareness: observations, interviews and surveys. These methods provided data to address the following research questions:

1. What engineering practices do researchers observe visitors exercising? (Related to a facet of procedural knowledge)
2. From a list provided, what engineering-related practices, strategies, and processes do visitors report engaging in while using exhibits? (Related to facets of procedural, factual, and conceptual knowledge)
3. In their own words, what terms do visitors use when describing the practices, strategies, and processes they are using? (Related to facets of procedural, factual, conceptual, and metacognitive knowledge)
4. Do visitors who described or are observed using engineering practices report that they are doing engineering? (Related to facets of procedural, factual, conceptual, and metacognitive knowledge)
5. Do visitors report that they are doing engineering while engaging with design challenge exhibits? (Related to a facet of metacognitive knowledge)

The instruments that explore the facets of engineering awareness capture the following indicators from learners:

- The variety of engineering practices, strategies, processes, and/or language they used during their experience (Related to facets of procedural knowledge).
- The engineering-related language they used for practices, strategies, processes (including synonyms) such as test, iteration, design, optimize, build, assemble, and performance (Related to facets of procedural and conceptual knowledge).
- The reported relationships between their activity and problem-solving processes and/or engineering (Related to facets of factual, and conceptual knowledge).
- The degree to which they reported that the exhibit was about engineering or required designing or building (Related to facets of metacognitive knowledge).

Methods

Setting

This research was conducted at the Oregon Museum of Science and Industry (OMSI), a large science center in Portland, OR. Data were collected during normal operating hours. Three exhibits were used in this study. The exhibits are described below and include copy panel language referring to terms for engineering and engineering practices that overlap with a broader set of terms and phrases researchers looked for in visitor language when coding interviews and observations for analysis; relevant words and phrases are underlined. Exhibits were cordoned off so that only the focal group used the exhibit during data collection.

The *Catch the Wind* exhibit challenged visitors to assemble and test a wind turbine using a hub, a variety of K'Nex® pieces, and plastic blades of different shapes. Visitors were encouraged to apply engineering to the real world concept of generating energy from the power of wind, and its relationship to sustainability. The copy included: "Engineers design wind turbines to capture as much wind energy as possible."

The *Build a Boat* exhibit allowed visitors to assemble a functioning boat that could be tested in a tank of water. Exhibit copy prompted visitors to consider the different real world needs of people in the design of their boat. The building station included hull pieces in different shapes and sizes, three shapes of sails, and cargo. The water-filled testing tank had an air blower at one end to provide propulsion, and obstacles and a finish line to make the activity engaging. The copy included: "Build a boat that can make it from the dock to the finish line!"

The *LEGO® Drop* exhibit challenged visitors to use materials such as pipe cleaners, pieces of pool noodles, paper, and string to protect a crate made from LEGO® from damage in a fall. This activity was framed within the context of a very real challenge: providing supplies to remote areas via airdrop. Visitors built their crate using supplies. Finally, they tested their design from three different drop heights. The copy included: "You are on a team of engineers working to design a new crate system to deliver food to earthquake victims." "Build the supply crate. Design a way to protect the crate from the fall. Test your design in the drop zone."

Participants

Participant selection focused on groups including at least one girl aged 9 to 14. Recruitment of participants used two strategies to engage participants within the target sample. The first strategy was to invite members of the public via social media to complete a screening questionnaire. Those groups that fell within the target audience were invited to schedule a time to visit OMSI to participate in the study.

The second strategy was to ensure that the research included representation from Latino communities (both Spanish speaking and bilingual English/Spanish). Based on recommendations from community partners and advisors, the second strategy included snowball sampling techniques to recruit Spanish/English bilingual participants. To help with recruitment, we contacted three local community partners who have connections within Latino communities. Additionally, we posted flyers in locations where bilingual Spanish/English speakers were likely to visit. Lastly, individual team members used snowball sampling in their own personal and professional networks to recruit participants.

Within the sociocultural perspective, project researchers framed visitor groups as learning groups. We collected data from 71 groups, including 22 groups that identify as members of a Latino community. Each group engaged with only one of the three exhibits described above. All recruitment, consent, assent, and data collection documents and procedures were available in both Spanish and English languages for youth participants and their guardians. We followed OMSI guidelines for collecting, managing, and analyzing data in two languages (e.g., more than one researcher is fluent in Spanish and English, instrument development includes members of Latino communities, data is collected in participants' preferred language(s) and is kept in the source language throughout the analysis).

Data collection

Observation

A one-page form was used to gather observation data. The form prompted observers to record the size and make-up of the visitor group, the date and time of day, and the name of the exhibit. Once a visitor interacted with the exhibit, observers recorded the time, tracked the number of unique designs that the focal group created (called the design version), and tallied observable operational indicators that the group engaged in during any given design version. The observation form also prompted observers to take open notes about what visitors said and did. This method focused on capturing facets of procedural knowledge. Inter-rater reliability was achieved through consensus during piloting of the instruments.

Interview

Guided interviews were conducted with the groups immediately following their exhibit interaction. Interviewers asked members of the group to describe what the exhibit was about, what they did at the exhibit, the steps they took, and the role(s) they played. Participants were interviewed as a group with questions posed to the youngest person in the group first and progressed through the group by age until everyone had an opportunity to contribute. Interviewers followed the preferences of the groups and conducted interviews in English, Spanish, or both languages. This method focused on capturing facets of factual, conceptual, and metacognitive knowledge.

Survey

A two-page written survey was given to visitor groups after they had completed their interview. The first four questions asked about the exhibit experience. One question pertained to satisfaction with the exhibit experience (modified from Packer [12]), and two questions explored facets of their engineering awareness. Question A asked visitors to report, on a five point scale from *Never* (0) to *A lot of times* (4), how often members of their group Defined a problem or goal, Made a plan, Built something, Tested something, Made improvements and Completed a challenge. For question B, visitors reported on a five point scale from *Never* (0) to *The whole time* (4) how often their group was: Having fun, Doing science, Feeling successful, Working together, Doing engineering, and Feeling frustrated. The order of the two awareness-related questions was varied across survey versions to eliminate ordering influences on the questions. Four demographic items were included on the second page of the survey to gather information about the ages and gender make-up of the group, the races and ethnicities of individuals, and the language(s) they spoke at home. Both Spanish and English versions of the instrument were available and groups selected the version they preferred. This method focused on capturing facets of factual and conceptual knowledge.

Analysis

Responses to interview questions were coded using a four point rubric. A single rating was given to the responses to all items from a single interview taken together. This gave a single rating of engineering language for the interview. Researchers read through all the notes of a single interview looking for engineering-related words. Words mentioned and their frequency were recorded. The list of engineering-related words mentioned and their frequency were reviewed and the interview was rated on a four point scale. Each interview was coded by two researchers in the original language (Spanish or English) and inter-rater agreement was achieved through consensus. These interview codes were entered into a spreadsheet and descriptive statistics were generated from the data (Table 1).

TABLE I

RATING DEFINITIONS FOR ENGINEERING-RELATED WORDS

Rating	Definition	Examples
1	Little or no mention of engineering-related processes	
2	Suggestions or references to engineering or design processes	Make, try out, made it better, fix, watch

3	Explicit naming of engineering or design processes	Plan, build, test, improve, iterate, brainstorm, observe, diagnose, refine, create
4	Explicit mention of engineering or a process involving explicit engineering or design processes	We built one, then kept testing and improving until we got it; the engineering process; we went through a design cycle

Responses to survey items were entered into a spreadsheet and descriptive statistics were generated for all items.

Observation data were reviewed for the presence or absence of five relevant engineering indicators as recorded on the observation sheet. Those indicators are: states a goal, discusses plans, attempts the challenge, modifies a design and completes a challenge. The total number of groups engaging in each practice by exhibit and across exhibits was determined and descriptive statistics were generated from the data.

Findings

The study found that participants overwhelmingly reported through the survey that they were doing engineering at exhibits. However, rather than use the term ‘engineering’ or describe an engineering process in open-ended interview responses, most groups simply implied or named specific engineering design practices such as building or testing. Variations between the three exhibit characteristics seemed to influence the likelihood that visitors would report engaging with engineering design practices.

Results

Participants overwhelmingly reported through the survey that they were doing engineering at the exhibit (mean score of 3.6 out of 4); over 95% of groups said they were doing engineering most or all of the time (Figure 2). Analyses of variance across exhibits found no significant difference for reports of “How often were those in your group doing engineering?” (Figure 3).

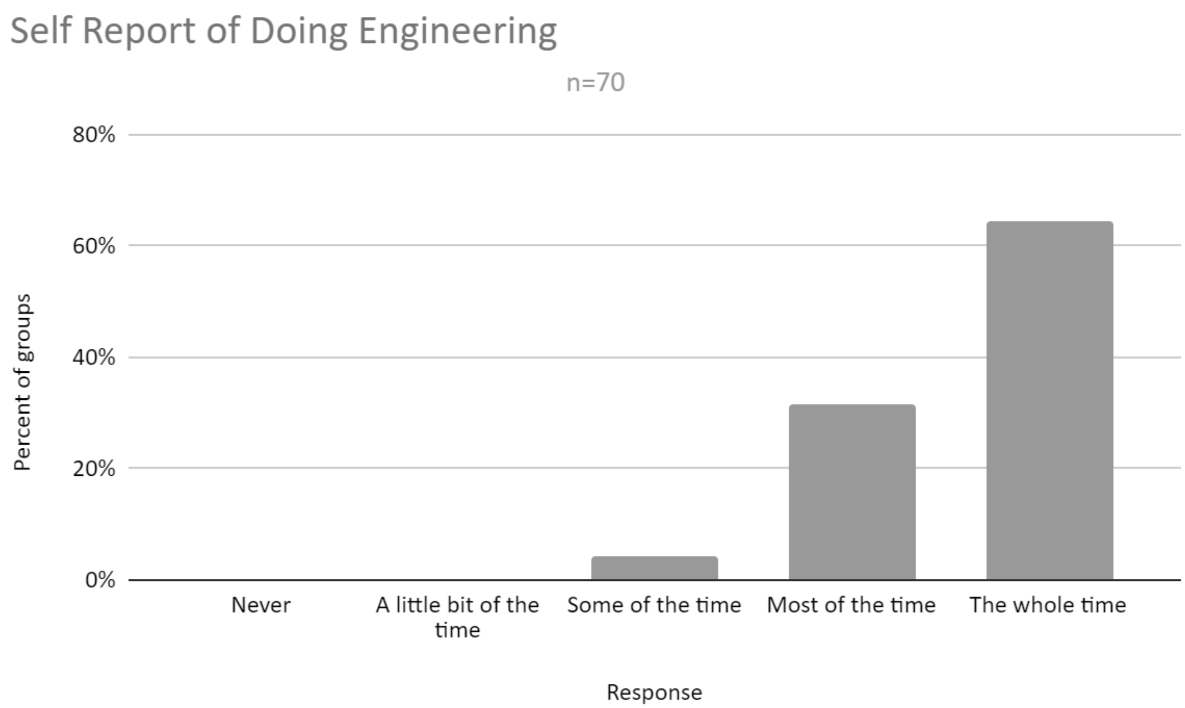

Figure 2. Frequency of responses to the survey question, “How often were those in your group doing engineering?”

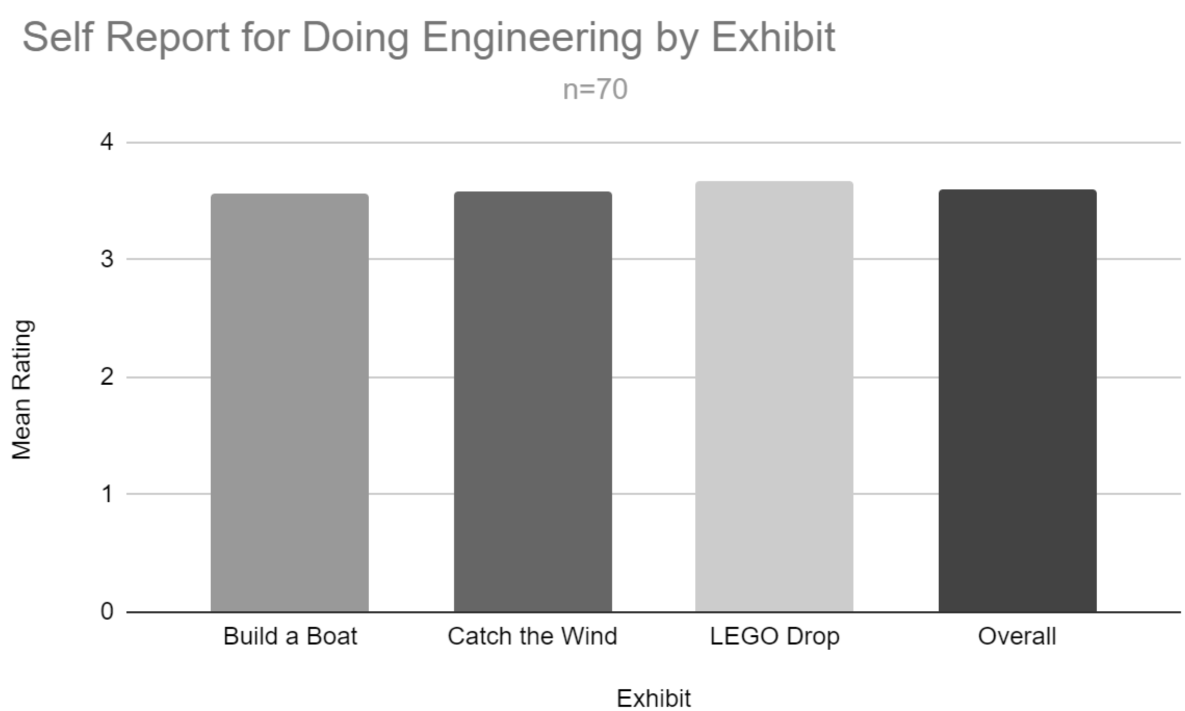

Figure 3. Analysis of the means indicated no significant difference across exhibits for responses

to the survey question "How often were those in your group doing engineering?" (0 = Never, 4 = The whole time)

Nearly all participant groups reported engaging in the engineering design steps listed in the survey questions. Build, Test, and Make improvements were reported more frequently than Define a problem, Make a plan, or Complete a challenge (Figure 4).

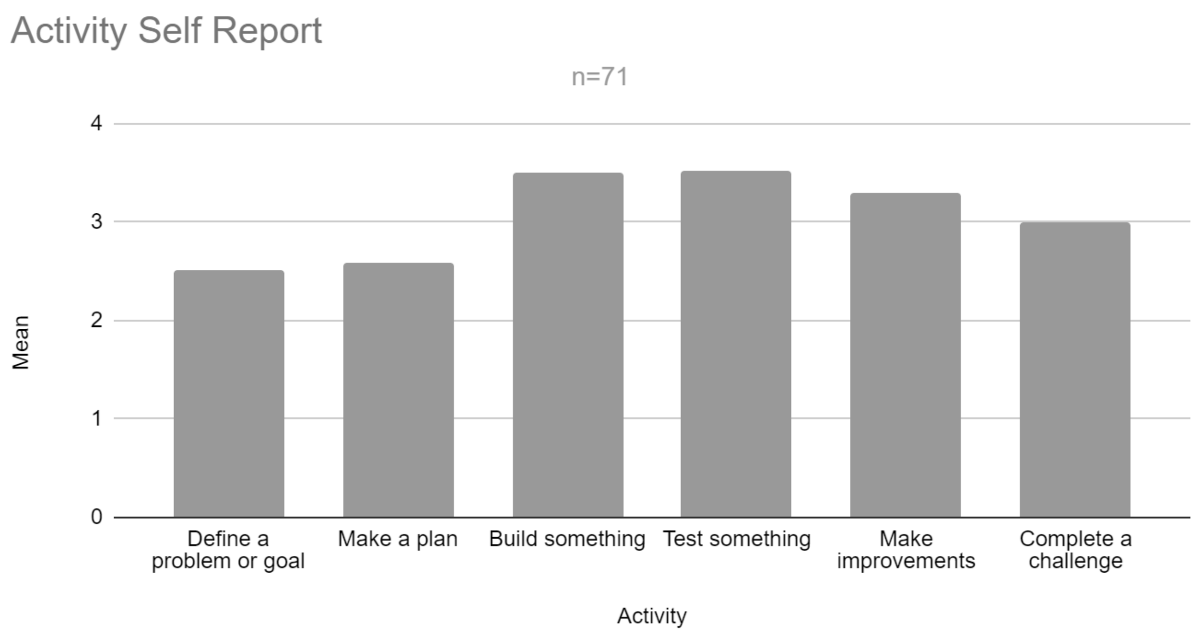

Figure 4. Means of responses to the survey question, "How often did the people in your group do the following?" (0 = Never, 4 = A lot of times)

The higher means for Build something and Test something are not unexpected. During a single design process, engineers often build, test and improve many times, while they likely define a problem, make a plan or complete a challenge less often. The pattern seen in the self report of engineering design steps is also consistent with the observation data which showed visitor groups engaging in more practices related to testing and improving designs than in defining problems and assessing goal completion.

In interview data, which included visitors' descriptions of what the exhibit was about and what they did, 30% did not mention any terms related to engineering or engineering-related practices. Only one group (4%) mentioned engineering explicitly. Most groups (43%) used colloquial terms and phrases such as *made*, *tried out* and *fixed* to describe what they were doing. Spanish speaking groups used terms such as *armar* (put together*), utilizar imaginación* (use imagination)*, crear diferentes combinaciones* (create different combinations)*, ver* (see)*, ingeniar* (create a plan) and *probar* (try or test).
Similar to the survey responses, words related to building, testing, and improving designs were

mentioned more frequently during interviews than words related to defining a problem, making a plan, or completing a challenge.

Results by Exhibit

Survey responses regarding engineering practices varied by exhibit, which suggests that different exhibits might encourage participants to engage in some engineering practices more than others. Data show that participants felt that they were defining a problem and building something more frequently at *Build a Boat* than at other exhibits, while groups at *LEGO® Drop* reported that they made a plan more often than at other exhibits. *LEGO® Drop* also showed lower frequencies of building, testing and making improvements (Figure 5).

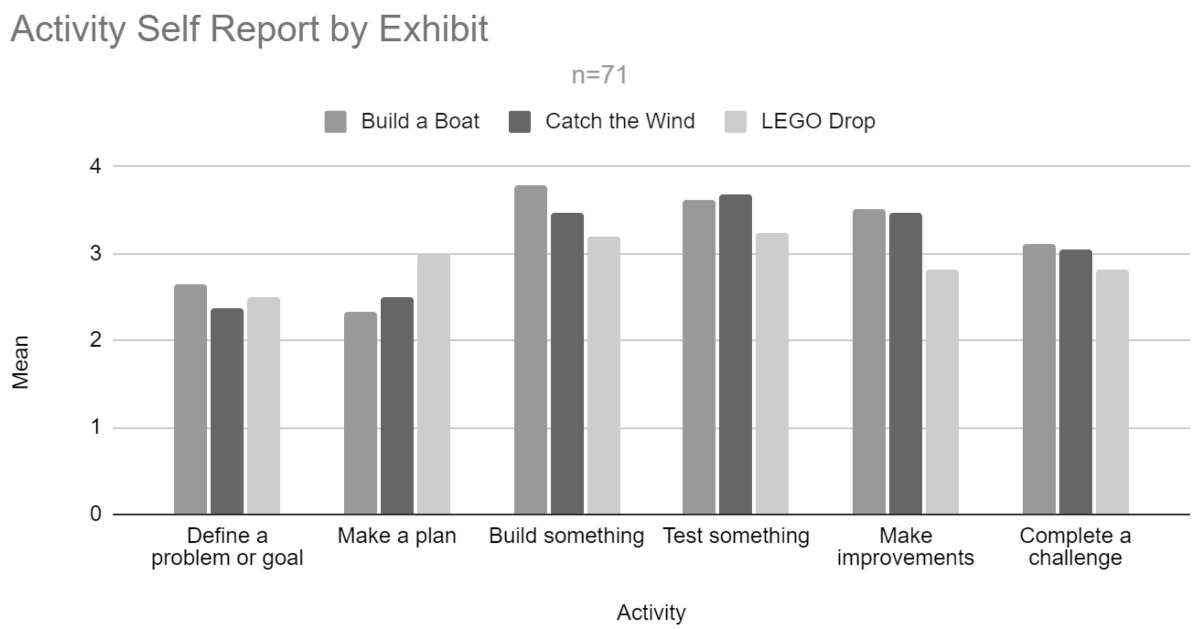

Figure 5. Means by exhibit of responses to the survey question, "How often did the people in your group do the following?" (0 = Never, 4 = A lot of times)

The use of engineering language in interview responses (n=49) also varied by exhibit. Visitors who had interacted with the *Catch the Wind* exhibit most frequently used language that made few to no mentions of engineering (60% of groups). Visitors who had interacted with the *Build a Boat* exhibit most frequently used language that suggested or referenced engineering/design practices (57% of groups). Visitors who had interacted with the *LEGO® Drop* exhibit most frequently used language that suggested or referenced engineering/design practices (50% of groups); 33% of groups at this exhibit also used language that explicitly named engineering/design practices; and one interview respondent explicitly mentioned the word engineering.

Discussion

This research was conducted prior to creating a 2,500 square foot exhibit to engage girls 9 to 14 years old and their families with engineering design practices and was intended to inform the exhibit design and development process by providing techniques to measure, and language to describe, facets of engineering awareness for three existing exhibits. The project researchers and educators value engineering broadly as an approach to problem-solving. It is an approach that includes not only the work of professional engineers, but also practices and strategies that people use or could use to address challenges in their personal lives and communities. We view the learning of engineering through a sociocultural perspective complemented by an education framework that describes procedural, factual, conceptual, and metacognitive knowledge as contributors to engineering awareness. Researchers considered the knowledge of visitors in the form of what they did (as observed by researchers) and what they reported (through surveys and interviews). The instruments and methods developed through this research build on prior work and offer additional contributions to larger conversations about the awareness of engineering by learners through informal educational activities. Based on the evidence in this study, this exploratory research offers these contributions to conversations in the field about awareness of doing engineering.

1. Visitors' awareness of engineering in their exhibit experience was strongly associated with the practices of building, testing, and improving and less strongly associated with the practices of defining a problem and making a plan. This was consistent across what researchers and educators might refer to as procedural, factual, and conceptual knowledge.
2. This study used two techniques to measure metacognitive knowledge related to engineering awareness.
    A. One technique to measure metacognitive knowledge related to engineering awareness was to ask people through a survey if they were doing engineering at the exhibits. We found this technique is low in value because it detected so little variation—almost everyone reported they were doing engineering despite variations in their sociocultural learning experiences.
    B. Another technique to measure metacognitive knowledge related to engineering awareness was to review all the self-reported interview responses for terms including and related to *engineering* (or in Spanish, *ingeniería*). This technique revealed only one instance of the word, *engineering*, and no instances of *ingeniería*; however, most groups named specific processes they were engaging in. This technique may have captured metacognitive knowledge related to awareness of engineering, but it will need further study along with additional ways to measure this knowledge to better understand the value of the technique.
3. Differences in the physical context, particularly features of the exhibit, can influence

facets of visitors' engineering awareness in the form of procedural, factual, and conceptual knowledge. For example, the exhibits in this study were stronger at fostering recognition of the practices of building, testing, and improving, and weaker at fostering recognition of the practices of defining a problem, and making a plan.

These findings offer insights into how researchers and educators might design studies and experiences that relate to awareness of engineering. These are discussed further below. Visitors' awareness of engineering related to their exhibit experience was strongly associated with the practices of *building*, *testing*, and *improving*; and less strongly associated with the practices of *defining a problem* and *making a plan*, as indicated by the low frequency that these practices were reported. Similarly, when provided with a list of steps in the engineering process and asked to report how often they engaged in each step, visitors reported *building*, *testing* and *making improvements* as those most used. While not as high as building, testing and improving, *completing a challenge* was reported more frequently than *defining a problem* or *making a plan*. This suggests that visitors may be less aware that they set a goal for themselves than the fact that they achieved what they set out to do. Another explanation of this difference may be that visitors felt that the challenge was defined for them by the exhibit text, though if this were the case, one would expect lower reported frequencies of defining a problem at *LEGO® Drop* where an explicit challenge was stated, and higher reported frequencies at *Catch the Wind* where there was not a challenge stated, but this is not what the data reflect.

Visitors' recognition of their engagement in engineering practices was consistent across what researchers referred to as procedural knowledge (doing) and conceptual knowledge (reporting). Their descriptions of what they were doing while at the exhibit were congruent with the observations of researchers. The consistency of visitors' self-report with the observation data suggests that visitors recognize they are doing engineering practices at these exhibits, procedurally and conceptually. That is, they have a good sense of what it means to participate in engineering practices such as building, testing and iterating, and that they know when they are engaging in those steps.

While visitors do report they are doing engineering design practices, it is less clear that they recognize that these practices are associated with the process of engineering. Through close-ended survey responses, participants overwhelmingly reported that they were doing engineering at exhibits; however through open-ended interview responses, most groups simply implied or named specific engineering design practices rather than use the term *engineering* (or in Spanish, *ingeniería*). This analysis demonstrated the complexities of language since there is no direct translation of the verb *engineering* in Spanish. While Spanish speaking researchers were looking for any engineering-related terms, it is not obvious what term or phrase Spanish speakers might actually use in this context to describe the act of "doing engineering." This study's measure of metacognitive knowledge related to engineering awareness from the survey is low in value because it detected little variation—almost everyone reported they were doing engineering despite variations in their sociocultural experiences. While visitor groups reported that they were doing engineering at the exhibit most or all of the time, the lack of variation in this item and lack of consistency between the survey item and the interview responses suggest that the survey item itself may not succeed at accurately capturing a facet of their engineering awareness. A likely explanation for the consistently high rating for doing engineering is that visitors reported doing engineering because they were in a science museum. This item also did not offer any opportunity to explore what it was about the activity that led visitors to report that they were doing engineering. For use in subsequent research, we have revised the survey to include a follow up question and revised the interview to include a follow-up prompt. The new item and prompt will ask visitors to identify what it was about the activity that led them to report that they were doing engineering.

Differences in the physical context, particularly the features of the exhibits, can influence facets of visitors' engineering awareness. Variations in the characteristics or the features between the exhibits seemed to afford different likelihoods that visitors would report exercising engineering design practices. That is, data regarding engineering practices varied by exhibit which suggests that different exhibits might encourage respondents to engage in, or recognise that they are engaging in, some engineering practices more than others. This supports the idea that the features of the exhibit, such as the exhibit text or the variety and placement of materials, and the design challenge activity itself may influence facets of visitors' engineering awareness. In the context of these three exhibits, building, testing, improving, and completing a goal were associated with physical activities and representations—which is a strength of hands-on science centers. In these exhibits, defining a problem and making a plan were not as explicitly represented by physical activities. This offers insights into future exhibit designs. This finding, and subsequent examination of exhibit features, have informed the development of new design challenge exhibits at OMSI. Based on this work, several strategies are being implemented in these new exhibits to increase visitor awareness of doing engineering.

In an effort to elicit more practices related to defining a problem and making a plan, exhibit developers are designing the physical arrangement of the activities such that testing areas are separated from building areas, and are introducing a wider variety of materials to use in designs. This is intended to slow down the planning and design process and increase conversations around material choice. To help assist visitors in making connections between the actions they take and how those practices can be labelled, developers are increasing the explicit use of engineering-related words in exhibit copy panels. These selected engineering-related words are commonly used in English and in Spanish so families can easily make connections in their everyday lives. Refined versions of the instruments and methods presented in this study will be used in a second research study to explore how implementation of the strategies described above and the addition of staff facilitation impact visitors' exercise of engineering practices and awareness of doing engineering.

In summary, to benefit researchers and evaluators, this research offers some useful ways to measure facets of engineering awareness in the form of procedural, factual, and conceptual knowledge gathered through observations, surveys, and interviews. The efforts to measure metacognitive knowledge related to awareness of engineering were not as clear. To benefit practitioners, this research suggests that these existing exhibits are stronger at eliciting recognition of building, testing, and improving engineering design practices than they are at eliciting recognition of the practices of defining a problem and making a plan. Designers and developers of engineering design challenges can use this knowledge to develop activities that are stronger at eliciting recognition of more practices in the engineering process.

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