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Learning about Learning and Engineering: Engineers, Students, and Educators Co-Design Challenges for a Science Center

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Abstract

We present two case studies of cross-community collaborations of museum educators, engineers from industry, and undergraduate engineering students tasked with co-designing engineering challenges for a science center's drop-in engineering tinkering program. Each collaboration worked over a semester to research, brainstorm, design, develop, implement, and refine design challenges that represent authentic design practices of the collaboration's industry engineers. The first collaboration involved engineering students from an education outreach club along with engineers from a software company, and the second collaboration involved engineering students from a product development course along with engineers from a sound reinforcement company.

Qualitative methods were used to study the collaborations through pre- and post-surveys, observations via video-recording and field notes, and artifacts (e.g., notebooks, write-ups, and presentations). We find that the various members of the collaboration contributed in different ways to the design processes: the educators contributed educational accessibility and the industry engineers and engineering students contributed engineering authenticity, both shaping the criteria and ultimately the final design challenge. Using a human-centered design process and engagement with visitors at the science center, the multidisciplinary collaborators grew to appreciate co-design as a mutual learning experience involving interaction and contributions from the learners. This implies the importance of engaging curriculum designers with the learners in-situ. The student teams rated that, as a result, they had increased awareness of community needs and were able to make a difference as engineers. The student teams' perceptions of engineering were reinforced, highlighting engineering as much more than a technical profession and stressing the accessibility and rewards of the engineering aspects of perseverence, curiosity, and creativity.

Introduction

To understand how to communicate and engage science center visitors in authentic engineering, we study a unique collaboration involving educators, engineers from industry, and engineering students in the design of educational tinkering activities. We build on prior work that has shown the positive impact of scientist-educator collaborations on learners.[1,2] In this paper, we research not just the learners (see prior publication on this[3]), rather here we focus on the engineers from industry and the engineering students as co-designers.

Past studies have explored how scientists have viewed their role in outreach as a one-way communication, in which they are transmitting important knowledge to the learners with minimal contribution from or personalization for the learners.[4-6] These outreach programs usually consist of face-to-face transmission of knowledge through table-top activities or talks. One program that further involved scientists in the design of exhibits and activities found that scientists abstractly described the communication as one-way, but they tended to describe specific past experiences in communication of science as a more context-dependent and individualized experience for the learner;[6] this finding is promising and suggests that these scientists may have explicit criteria for what they abstractly believe general education and communication should consist of, while they employ different criteria implicitly in the actual educational situation that better reflect the educators' model of learning.

In this study, with the unique context of an open-ended and self-driven tinkering environment and the student teams' use of a *human-centered design*[*] approach, the collaborations benefitted from multiple types of communication and interaction. We explore the processes in which the cross-community designers engage to deconstruct their engineering practices for visitors, and we evaluate their perceptions of learning and engineering as reflected in their criteria for "good" engineering tinkering activities.

Prior Literature

Interdisciplinary Collaboration Between Educators, Scientists, and Engineers

As they are widespread and accessible, informal science centers are well positioned to inform the public of current science and engineering. Science centers need engaging educational content to create visitor programs that are relevant, integrated, and dynamic. At the same time, they ideally need to have an adaptable learning environment with updatable content.[7] Our research is based on the premise that science centers can sustain these types of programs through collaborations with professional scientists and engineers.

Multidisciplinary collaborations in public outreach can offer mutual professional development,[8] with scientists and engineers gaining communication skills while sharing their work with the public. Science center educators benefit from gaining new programs and exhibits that are contextualized in the technical fields while maintaining educational values.[9] Past collaborations have found that scientists and engineers enjoy the experience and increase communication skills.[6,9,10] Furthermore, scientists can increase their exposure to new ideas that may help in their own professional work and thus gain professional recognition.[10] In an evaluation of one collaboration, scientists reported that the collaborative experience was fun, rewarding, and satisfying, and that they could apply the skills gained to other settings; scientists appreciated the opportunity to communicate work to the public.[2] In a review of corporate social responsibility, in which employees volunteer for and companies support community service, Fombrun, Gardberg, and Barnett claim that employees gain a "broader repertoire of cultural, relational, and self-leadership competencies."[11]

Furthermore, these collaborations can be beneficial to the learners in many ways: the public gains positive attitudes towards science and engineering,[1] view the technical fields as more approachable and relevant,[10] are more aware of previously unknown careers, and retain science concepts.[2] However, despite the strong support for such scientist-educator collaborations,[6-9,12-14] these collaborations can often be difficult for science centers because of the scarce resources required to keep these non-profits constantly updated,[7] a negative peer professional image of

[*] The human-centered design process involves gathering, interpreting, and organizing data on user needs for a product or service and incorporating these findings into the design and development of the product or service.[45] The distinction from other design processes is that this process is driven by user needs, subject to other considerations such as engineering or environmental factors.

scientists and engineers who take time out to help these educational programs,[10] and the challenge to translate professionals' practices to something accessible and understandable to a quickly passing visitor.[4]

One approach called *Portal to the Public* aims to overcome some of these obstacles and provides a framework for science centers and museums to engage with scientists, engineers, and researchers.[9] The framework, the authors emphasize, is not a "one-size-fits-all" approach, but rather acknowledges the idiosyncrasies of each setting. Professional development is key to *Portal to the Public*; science researchers are trained by museum educators and are then given opportunities to translate their current research for museum audiences.

In our study, the additional engagement of students with the professionals provides an avenue for the education of the public that further overcomes some of these obstacles by providing a service learning[15] project for students to undertake substantially, minimizing the time required by the professionals and educators while engaging students in a consequential engineering design task.

To understand the student-engineer-educator collaborations studied in this paper, we refer to Bronstein's model for interdisciplinary/multidisciplinary collaboration,[16] which describes key components that contribute to the success of such collaborations. Her model was developed specifically for social workers but is applicable to the field of education with its similar focus on service to society. The key components are (1) *interdependence* such that team members depend on other members with unique expertise and maximize creativity through integrative teamwork, (2) *newly created professional activities* such that specific outcomes are created that cannot be created independently, (3) *flexibility* such that members compromise and react creatively to disagreement and unexpected issues, (4) *collective ownership of goals* such that there is a shared responsibility among team members through the joint design, definition, development, and achievement of shared goals, and (5) *reflection on process* such that self-evaluation and feedback are formalized as part of the collaboration efforts.

Service Learning

Service learning provides an opportunity to incorporate real-world experiences into the engineering curriculum while providing a valuable service for an entity such as a nonprofit organization or a disadvantaged community.[17] It allows students to actively practice their design and engineering skills in a real-world setting.[17] The National Academy of Engineering has found that academic programs that engage students in team exercises and design challenges that connect to real-world problems are most successful in retaining its engineering students.[18] Students engaged in such experiential learning opportunities have better retention of technical knowledge and are better able to apply what they have learned in college courses to real life situations after graduation.[19-23] These benefits of service learning are reflected in the ABET criteria for engineering accreditation at colleges.[24-26]

Moreover, service learning and professional skill development has been shown to have a positive impact on women engineers and may improve recruitment and retention of women in the field of engineering at the undergraduate level.[24,27-30] Additionally, the collaboration studied in this paper involves students with professional engineers, thus connecting the students to practicing experts as mentors. Mentoring is known to be a method to increase retention and persistence of women and minorities, especially in the STEM fields.[31-33]

Context

The context is the Ingenuity Lab program at the Lawrence Hall of Science, a public science center of the University of California, Berkeley. The Ingenuity Lab provides open-ended tinkering design challenges to drop-in visitors. The majority of children who visit are between ages three and twelve. The Ingenuity Lab is held in a large classroom space at the Lawrence Hall of Science, allowing visitors to come and go as they wish; the average stay time is over 30 minutes. Each month, an engineering design challenge is presented along with appropriate materials. Past challenges include *mechanical grabbers*, where visitors use sticks, rubber bands, wires, tubes, string, and sponges to create grabbers to pick up objects and *boats*, where visitors use paper, pennies, foil, tape, balsa wood, and string to design boats to float and sail.

The Cross-Community Design

This study builds on the current Ingenuity Lab program by developing and implementing a cross-community collaboration model with practicing engineers from industry, undergraduate engineering students, and educators (informal science and engineering) to develop open-ended engineering design challenges. Previously, two educators without engineering experience developed the engineering design challenges at the Ingenuity Lab. Because visitors come in with little awareness of the relevance to real-world engineering,[34] we were able to take advantage of local experts to highlight the engineering relevance in co-designed activities.

Our case studies review the design and implementation of two new challenges, representative of the engineering work of two companies, a local software engineering company and a sound reinforcement engineering company. Each was developed by two separate collaborations. Table 1 provides descriptions of the two challenges.

Research Questions

We study these two multidisciplinary collaborations through their design processes and the roles of the participants, focusing on the development and negotiation of their goals and criteria throughout the design and refinement of the design challenges. We seek to understand the processes with respect to the engineering students' and practitioners' perceptions of learning and engineering. We also study the final concepts in their implementations as design challenges at the science center. In particular, the driving research questions for this study are:

(1) What were the two collaborations' design processes, and how did the collaborations' goals and criteria shape the processes?
(2) How did the design experience influence the collaboration members' perceptions of learning and engineering?

Table 1: Descriptions and examples of each challenge.

Challenge	Example
Engineer the World: Design your own paper prototype for a website or mobile app, then implement it on the computer with help from staff.	
Sound Engineering: Create and change sound by making a loudspeaker or instrument using recycled materials, coils of wire, magnets, and rubber bands. Staff assist in testing speakers.	

Methods

To understand the design processes of the collaborations and their perceptions of learning and engineering, we qualitatively studied them through pre- and post-surveys, observations via video-recording, and artifacts, including notebooks, write-ups, and presentations. Surveys were given at the beginning of and after the collaboration experience. Questions covered participants' background, perceptions of engineering, expectations and contributions, reflections on implementation with visitors, and perceived impact of the experience on themselves as engineers. Collaboration members were also given an opportunity to express any other comments or questions anonymously in the surveys. The post-survey further included questions to rank agreement with various statements on the impact of the experience. See Appendix A for the complete survey questions. Videotaped observations were conducted during all meetings of students, engineers, and educators, and artifacts pertaining to the design processes were collected from the students after the collaboration.

For analysis, data from artifacts were triangulated with the survey and meeting data to create progressions of the design processes, focusing on the development of criteria for the design challenges, the ideation processes, and the engineering students' and practitioners' beliefs about engineering. The matrix progressions highlight how each team member participated with respect to the ideas contributed and how criteria for the activities were developed. The ideas and criteria were extracted from the progressions in an emergent analysis to understand the trajectory and evolution of the main themes throughout the design processes.

Participants

The first collaboration that created Engineer the World consisted of two engineers from Google, a software engineering company; five sophomore-year engineering and physics students from the University of California, Berkeley; and two educators from the Lawrence Hall of Science, including one of the co-authors as an embedded education researcher. Three out of the five students had previously volunteered in the Ingenuity Lab, while the Lab was new to the other two students and the two engineers. The students participated voluntarily through an engineering education outreach club and for course credit during Fall 2012.

The second collaboration created the Sound Engineering challenge and consisted of one engineer and one technical support specialist from Meyer Sound, a sound reinforcement engineering company; five junior- and senior-year engineering students from the University of California, Berkeley; and two educators (the students' product development engineering instructor from the university and an embedded education researcher from the Lawrence Hall of Science). Three out of five students had taken a previous course that included a project or exhibit at the Lawrence Hall of Science, while none of the other students and engineers had any prior experience with the science center. The students individually selected this collaboration for their product development engineering course project during Spring 2013.

All collaborators met five times over a semester (three months) in 1-3 hour blocks. Students carried out the bulk of the project with the engineers from industry serving as mentors and educators serving as advisors. The student teams also met separately in many additional meetings during the design process. The first two months generally consisted of background research, brainstorming, and prototyping while the last month was implementation of the challenge, including refinement through feedback. The embedded educational researcher used the collaboration meetings to perform formative assessments. The Sound Engineering collaboration's process was further structured by the associated product development engineering course, with deadlines and constraints built in for their course project.

The initial recruitment documents for both collaborations are included in Appendices B-D. To introduce and provide basic training on informal learning, particularly at the Ingenuity Lab, an educator from the Lawrence Hall of Science provided an overview of the Ingenuity Lab with examples of past challenges, the Lab's learning goals, and the historical context of the Lab during the first meeting for both collaborations. This initial meeting, held at the Lawrence Hall of Science, further engaged the collaboration members in the current design challenge at the Ingenuity Lab so that they could participate as visitors would and observe the visitors in the space; this was followed by discussion of their experiences and observations, particularly their thoughts on criteria for a good challenge. Meetings following the first meeting consisted of further human-centered design research, brainstorming, idea selection, and prototyping. The final collaboration meeting occurred during the months of implementation to discuss feedback and reactions. The students gave a final 5-10 minute presentation to communicate their process and final challenge. The Engineer the World collaboration spanned September – November 2012 and was implemented in November 2012 with over 611 visitors participating. The Sound Engineering collaboration spanned February-April 2013, with implementation during April 2013 with over 886 visitors.

Findings

Design Processes: Interdisciplinarity Contributes Accessibility and Authenticity

Bronstein's collaboration model[16] offers five components that lead to the success of collaborations that involve multiple disciplines: interdependence, newly created professional activities, flexibility, collective ownership of goals, and reflection on process. For the two collaborations in this paper, we look at how these play out with respect to the overall design process, focusing on the ideation process and criteria developed, as well as with respect to their perceptions of engineering and learning. By the context of the collaboration, we note that interdependence and newly created professional activities are set up respectively in terms of the unique expertise of the college students, industry engineers, and informal educators that make up the collaboration and the goal to develop a new engineering design challenge for the science center. We analyze the collaborations' design processes to determine how flexibility, collective ownership of goals, and reflection on process occur.

Team Roles

The roles of the students, engineers, and educators were similar in both collaborations, and the interplay of the roles shows the interdependence of the team members. The students participated in a creative role, taking on the bulk of the design process through brainstorming, testing, implementing, and refining the challenge. They flexibly carried out these processes with help from the industry engineers in a mentor role and from educators in a logistical role. The engineers brought up questions in meetings that really probed and defined the criteria, pinning down the nuances and forcing the team to reflect on what was necessary or not. Thus, they helped refine the criteria by pushing for specifications as in real engineering practice and turned the design process into a more authentic learning experience. The educators were very strict with the timeline and logistics, as the challenge was scheduled to be delivered to the public for a set month. In particular, one educator pushed very persistently to have the materials ready sooner, which meant that the challenge idea needed to be decided earlier. The educators from the science center also played a greater role in the implementation than did the engineers. Their experience with the program along with the goals of the science center led them to emphasize certain criteria: accommodating for a wide age range, appealing to both boys and girls, and fostering collaboration across generations. Both the engineers and educators were also more critical of ideas, providing different perspectives and feedback for the student teams, and forcing them to think flexibly. They provided guidance with suggestions on how to proceed with ideas. As a whole, the students were in greatest control of the design process, though the educators heavily guided and enforced logistical constraints while the engineers had least control but still guided the students and contributed key ideas. Consequently, the educators contributed educational accessibility while the engineers and students contributed engineering authenticity.

Goals and Criteria

The collaborations needed to establish a clear set of objectives, reflecting collective ownership of goals, in order to successfully work together. Through analysis of the collaboration meetings and documents, we found that this collective ownership was established early on for both collaborations and set the ground for very smooth ideation processes.

Both collaborations, very early in their design processes, came up with goals and criteria around what a "good" challenge for the Ingenuity Lab should be. The Engineer the World team maintained their initial criteria, while the Sound Engineering team evolved their criteria. Analysis of the data demonstrates that two sets of criteria were formed to achieve the objectives of the collaborations – an implicit set and an explicit set. The explicit set emerged when the collaboration explicitly listed the project's needs, which they identified and agreed upon as a group, while the implicit set came about informally through conversations and personal notes.

Engineer the World: Show What Engineering Is and "Engineering is for Everyone"

For Engineer the World, the objectives were established in the very first introduction meeting, initially asserted by the educators. One educator stated that she wanted to "make explicit connections between the actions of participants and the work of professional engineers" in the program (authenticity) while another stated that she wanted to "show that engineering is for everyone" (accessibility). The students and engineers further discussed the meanings of and ways to achieve authenticity and accessibility, consequently maintaining the need for guidance, personalization, and flexibility to allow for contributions and learning from both the facilitator and visitor for mutual learning experiences.

During this first meeting, the educators and engineers from industry contributed much of the criteria. The educators contributed criteria for accessibility for all ages and genders, showing engineering is for everyone, as well as more pedagogical concerns. One engineer from industry discussed criteria from observations of visitors: have a topic that's familiar, display example solutions, include a decoration component for younger visitors, provide an exciting test for the solution, and offer a flexible timescale. Another engineer from industry added from her own experience and passions about engineering education; she suggested the challenge should show that engineering involves helping people and can be social. She stressed that it was important to make the challenge personally relatable with appropriate guidance. The students each contributed at least one criterion: allow for individual and group work, be open-ended for various paths and solutions, have a variety of materials for creativity, and offer tiered levels of challenges for different ages.

Table 2: Criteria for engineering design challenges for both collaborations, including criteria both explicitly identified by the entire team and implicitly identified through informal discussions and personal notes.

	Engineer the World	Sound Engineering
Explicit: Initial	• Allow for individual work and collaboration across generations • Parents have some familiarity with the topic • Lots of different outcomes and ways to engage • Have examples for inspiration and allow for cross-pollination • Use materials that allow for personalization, use familiar materials in unfamiliar ways • Offer decorative components for young kids • Be museum specific, but also have a take-home component • Provide a flexible timescale - allow for many short iterations for improvement, make success attainable • Should be exciting to test • Show that engineering is broader, not just mechanical • Be gender neutral • Build on prior knowledge and interests • Relate to kids' personal/daily lives • Provide tiered levels of challenges for different ages • Facilitate with varying intensity • Have stations with instructions that are progressively more complex • Have instructions to create a toolkit of fundamental elements to build with	• Fun and informative • Interactive in a "hands-on" fashion • Allows individual user to create unique solutions • Goal-oriented • Allows user to cycle between testing and tuning their design • Minimal wait time and fast feedback • Applicable for a range of ages • Gender neutral activity • Rewards teamwork and collaboration • Cheap, reusable supplies
Explicit: Final	Same as above	• Fun and informative • Hands-On • Goal-oriented • Iterative Design • Fast Feedback • Allow for creativity • Gender and Age Neutral • Sustainable
Implicit	• Fun/interesting • Challenging • Rewarding • Inspiring • Goal/design oriented/challenge to be solved	• Simple • Challenging • Rewarding • Adequate materials • Relate to personal/real-world • Social • Inspiring • Guidance • Modularized • Unusual/novel • Attractive and dynamic • Take-home • House-hold/familiar materials • Spacious, clean • Examples

Five implicit criteria appeared in meeting conversations and student notebooks that were not mentioned during the initial discussion of criteria. These implicit criteria may have developed naturally in the space or were implied by other criteria; thus, these criteria were never explicitly articulated. For instance, the design-build-test cycle represents the engineering authenticity that the team strived for, and the team noted their observation of this process in implementation. See Table 2 for the list of all criteria.

Overall criteria that appeared most frequently involved showing that engineering is for all ages and genders, allowing for creativity and personalization with materials, making the challenge personal and real-world related, and providing guidance through facilitation. Thus, the Engineer the World criteria heavily emphasized accessibility, focusing on the learner experience as a mutual experience between the learner, facilitator, and context while aiming to represent the authentic processes of engineers.

During the final meeting for the Engineer the World collaboration, one of the students mentioned that they achieved accessibility through projecting children's websites on the wall; when other children saw these websites, they got more "enthusiastic because they realized if she can do it, then they can do it as well." Another student nicely summarized the achievement of their initial objectives on making the engineering content authentic:

> *"One of the things that I realized that was really helpful about this project is teaching them about what engineers really do, the whole design and then [actually] applying their ideas to actually making it happen, and I think we were really able to show that aspect [...] but I think also in engineering in general, regardless if programming is involved, there's always that same process where you have to come up with an idea, and then you have to think about what you do, and then ultimately lead to whatever goal that you want to achieve."*

<u>Sound Engineering: Moved from Passive to Active, Inclusive, and Sustainable Learning</u>

Table 3: Sound Engineering team's evolving mission statement (bold emphasis added).

2/12/2013	2/26/2013	3/21/2013	5/7/2013
To **demonstrate** and **disseminate fundamental knowledge** of engineering, **through sound** engineering, to a **young audience** and **inspire** them to pursue a STEM field.	A challenge at the [science center program] which **demonstrates** the **fundamentals of sound engineering** to the **users**.	To **design** a **hands-on** engineering challenge for the [science center program] in order to **inspire users** and **teach** the **fundamentals of acoustics**.	To **design** a **hands-on** engineering challenge for the [science center] in order to **inspire** and **teach children** through sound

As part of the course project, the students from the Sound Engineering collaboration had developed a mission statement for their objective. As can be seen from Table 3 their mission statement evolved throughout the process in three distinct ways. First, it evolved from a more passive one-way to an active two-way engagement of learning, going from "demonstrate" to "inspire" and "teach" with "hands-on." Second, the mission statement initially referred to visitors as a "young audience" and "users" but eventually referred to them in a more personal way as "children." Finally, the learning goal evolved from focus on the end-goal of learning specific concepts towards focus on the learning process for sustained interest. The goal began as disseminating "fundamental knowledge of engineering" which evolved to "fundamentals of sound engineering" then "fundamentals of acoustics," and ultimately evolved to "inspire and teach children through sound" with the content as a means to long-term learning and inspiration.

Unlike the Engineer the World collaboration, the Sound Engineering's criteria came almost exclusively from the students, with engineers pushing for specifications of the criteria. Explicit criteria, developed as user needs for the course project, focused on goals of the activity for all stakeholders: visitors, engineers, and the Lawrence Hall of Science. These criteria also included specific methods to achieve accessible visitor engagement and authentic engineering experiences. The Sound Engineering's final explicit criteria were fun and informative, hands-on, goal-oriented, iterative design, fast feedback, allow for creativity, gender and age neutral, and sustainable.

Implicit criteria (see Table 2) mostly focused on the visitor experience, particularly on what visitors want and how to keep them engaged. This represents an understanding of the learning process as a mutual, rather than a one-way, experience,[4-6] in incorporating visitor needs and backgrounds. These criteria came from participating in and observing the Ingenuity Lab, as well as interviews with visitors. For example, Sound Engineering's students implied criteria for guidance, accessibility, attractiveness, and challenge.

The criteria evolved and had varying emphases throughout the design process. Overall, the criteria of hands-on and multiple solutions for personalization were very prevalent throughout the process, emphasizing accessibility as a mutual learning experience similar to the Engineer the World team. Other criteria were more commonly identified in the science center space: guidance, fast feedback, goal-oriented, and cheap and reusable materials. On the other hand, user interviews and the educators contributed the criteria of age and gender neutral as well as collaboration, and course lectures emphasized the concept of sustainability.

<u>Summary</u>

Both collaborations developed explicit and implicit criteria. The Engineer the World collaboration created a broader set of explicit criteria at the beginning of their design process, heavily guided by the engineers and educators, while the Sound Engineering collaboration came up with their criteria more independently from the engineers and educators. However, both collaborations acknowledged the need to make the challenge accessible and authentic, and in particular understood the need to make the experience a mutual learning experience with contribution and interaction from visitors. They emphasized a hands-on experience, guidance from facilitators, catering to all ages and genders, allowing for personalization through multiple paths and solutions, relating to personal and real worlds, and providing feedback through quick iterations. Many of these were implicit criteria for the Sound Engineering collaboration, while the Engineer the World collaboration included many of these in their explicit criteria. However, both collaborations strived to achieve both their explicit and implicit criteria in their final design challenge to provide the public with a mutual learning experience.

Thus, in order to translate their implicit engineering practices to explicit practices for visitors, the participants in the collaborations negotiated a play between explicit and implicit criteria. Not all criteria were explicit, and notably criteria acknowledging the mutual learning experience were mostly implied from the learning context, many of which took precedence over the explicit criteria. Therefore, in designing these activities, designers should engage with learners in-situ in a human-centered design process to recognize important criteria that guide the design of the learning activity.

Themes in the Ideation Process

The ideation processes for both collaborations were surprisingly smooth. The early establishment and agreement of criteria created collective ownership of goals in selecting ideas. Ideas initially were heavily influenced by the actual products of the engineering companies involved; however, ideas soon branched out even broader within the topic areas of computer science and sound. Ideas were contributed by all members involved in the collaborations. The Engineer the World collaboration collectively voted for the top ideas while the Sound Engineering collaboration individually selected their top three ideas and obtained customer and user feedback before voting on the final. Coincidentally, both collaborations decided to combine their top two ideas into one challenge.

<u>Incorporating Flexibility and Feedback</u>

Because the Engineer the World collaboration established collective ownership of goals early on, there was very little disagreement throughout the process. They were particularly flexible in incorporating feedback from reflections with visitors, educators, and facilitators. In particular, their big theme goals were reaching all ages, attracting girls, fostering creativity, relating and connecting the activity, and representing the engineers' actual processes. The engineering students believed that they had successfully achieved their goals: children of all ages and genders felt like they could do the activity, especially after seeing other children's websites; visitors were given complete freedom to creatively design any type of website or app; visitors commented on the activity's real world connection; and children engaged in the same process as the engineers in designing a website or app.

The Sound Engineering students incorporated flexibility through modularity of components in order to make the design easy to assemble, easy to take apart, easy to customize, easy to modify, and easy to reuse. Thus, modularity helped them to achieve half of the team's criteria: iterative design through easily disassembling and modifying, creativity through scaffolding components for a variety of designs, accessibility for a wide variety of ages through easy assembly, and sustainability through ease of reuse. Based on feedback from the educators in regards to promoting interaction, the engineering students also sought to provide a mutual learning experience for the visitor with the concept of DIY, or do-it-yourself. Students heavily emphasized DIY in the sense that the challenge would be a hands-on interaction for the visitors, in which they could create their own design, rather than following a prescriptive method, again acknowledging contributions from the learner. Specifically, they referenced their top two ideas as "DIY speakers" and "DIY instruments."

Understanding Education as a Mutual Learning Experience

The processes used in the collaborations to create the learning experiences reflect the members' perceptions of learning. We saw that both collaborations heavily emphasized accessibility and authenticity, in particular achieving accessibility through a mutual learning experience involving guidance, personalization, and flexibility in ways to engage in a variety of solutions. Both collaborations shared the goal of engaging visitors in authentic engineering; in pre-surveys, Engineer the World emphasized teaching communication and teamwork as important parts of engineering, while the Sound Engineering focused on the process of developing solutions. For instance, Engineer the World responses include:

> *"I believe that engineers should teach these people that engineering is not just building new contraptions. It is a skill which people can apply to a number of jobs."*
>
> *"Engineers need to teach other non-engineers that engineering is not just about problem solving but collaboration and communication of ideas among multiple individuals."*
>
> *"How it involves lots of creativity (not just doing certain protocols over and over again) and applying what you know to a different problem each time"*

While Sound Engineering responses include:

> *"The pulling in of knowledge to develop something meaningful."*
>
> *"We should teach engineering to be the discipline of translating scientific knowledge to usable consumer products."*

In pre-surveys, particularly engineers from both collaborations stressed showing the accessibility and broadness of engineering, including the various "career opportunities."

As a result of the implementation of criteria around accessibility and authenticity, visitors engaged in mutual learning experiences. In post-surveys, collaborators report that visitors learned about the accessibility of the engineering topics as well as basic technical concepts for each challenge. An Engineer the World student said that visitors "have learned that anyone can learn to program," and a Sound Engineering student described that visitors learned "[h]ow to build speakers, how easy it is to demonstrate basic science principles, that technology is not necessarily complicated, and plenty of acoustics principles." In particular, visitor experiences in both challenges depended heavily on facilitation. The Engineer the World collaboration spoke about using facilitation to show visitors that making websites and apps is accessible and doable and to connect the topic to familiar ideas, culminating in a rewarding outcome in the final implementation of visitors' designs. An engineer from industry said, "I've realized that parents can sometimes judge too quickly if their child can or cannot do something, so I think the facilitators can recognize these types of parents and try to get them to re-evaluate the situation again and not assume that the challenge is too hard for their children." While the Engineer the World collaboration focused on implementation, the Sound Engineering collaboration described facilitation through timely and friendly interaction with visitors; the success of visitors depended mostly on testing and refining through feedback from both the tests and the discussion of results with facilitators. They emphasized accessibility through multiple paths and solutions during the testing and refining steps of design. Thus, both collaborations noted how the challenges were accessible to visitors through a mutual feedback process, in which facilitators played a key role.

Engineering Identity: Engineering Involves Much More Than Technical Skills

As shown in the previous section, both collaborations initially emphasized non-technical aspects of engineering they wanted to teach visitors. We note that pre- and post-surveys do not show much change in perception of engineering for either collaboration. Engineer the World defined engineering as applying math and science to solve problems to help society, and Sound Engineering defined it as using prior knowledge and science to design and build products to benefit society. Both collaborations strongly emphasized problem-solving and societal impact in the pre- and post-surveys. Creating such solutions is the rewarding motivator in engineering. One engineer mentioned the process: "Engineering has a strong emphasis on process and this presentation taught that lesson quite well; that there is a process to which scientific creations can be accomplished." Both collaborations also mentioned creativity as part of the definition of engineering. Although they noted that technical knowledge was needed, they emphasized the importance of process, societal impact, and creativity.

In terms of how well the collaborations thought their final challenge taught engineering, both matched their definitions of engineering to the visitor experience in the challenge. Engineer the World mentioned that visitors were given the freedom to creatively design something in software development, an area not necessarily encountered by most visitors. One engineering student said, "The challenge teaches engineering by giving students the building blocks of creation, from which they can progress their own designs." Sound Engineering noted in the post-survey that their challenge gave some science background, then allowed visitors to apply that knowledge to solve a problem and engineer a design through a process. One engineer from industry said, "The lab activities were examples of converting an electrical or mechanical energy into sound in air. Working with the available materials to create a system to do either, requires solving several problems, engineering a solution." Thus, Engineer the World emphasized creativity while Sound Engineering emphasized the design process.

More interesting details about their perceptions of engineering came from responses to the survey question: "What are attributes and characteristics of a good engineer?" Although there was not much difference in the responses between the pre- and post-surveys, very few people mentioned technical skills and no engineers from industry mentioned technical skills. In fact, most attributes mentioned were hardworking, determination, curiosity, willingness to learn, and creativity. These types of attributes are in line with the malleable mindset,[35] in which intelligence is not something people are born with, but rather achieved through hard work and perseverance. This finding is surprising given that a common perception is that engineering is difficult and requires innate technical ability.[36,37] Specifically, Engineer the World heavily emphasized creativity, and Sound Engineering heavily emphasized communication in the pre-survey and problem-solving in the post-survey. When self-identifying their own strengths and weaknesses, the industry engineers from both collaborations named technical skills as their weaknesses; one engineer from Sound Engineering said his weakness was "differential equations" while an engineer from Engineer the World said her weaknesses included “algorithms” and “low level systems.”

Engineering Students and Practitioners Value the Experience, Feeling Like They Contributed Substantially to a Consequential Task and They Gained Professional Skills and Real World Experience

In post-surveys, all engineering students and practitioners stated that the experience met or exceeded their expectations, with both collaborations emphasizing the actual implementation of their design challenges as the valuable component. They emphasized that the collaboration design experience allowed them to increase professional skills, gain real world experience, and have an impact on the public, which could all be attributed to the actual implementation with the public. The engineering students cited increased understanding of design processes and the greater real-world relevance (see Table 4). Engineer the World focused more on education and teaching, while Sound Engineering focused more on implementation of their design. Engineer the World noted that they were able to work together and create something from scratch, similar to engineers’ actual practices. They discussed collaborating with those from different backgrounds and needing to come to a consensus to implement the challenge, learning how to teach engineering, and seeing their impact on education. Both industry engineers from Engineer the World were surprised that the challenge was able to cater to a wide range of ages. Sound Engineering emphasized the value of participating in the design cycle in full form, especially the implementation. The students further mentioned the value of working with various stakeholders and diverse people, performing under real deadlines, having interactions outside of the university, and brainstorming with industry engineers. The engineers from industry found the experience rewarding because they were able to reach out to the public and teach them about their jobs; an engineer from Sound Engineering noted the value of having a real impact on education. Finally, the educators gained from the expertise of the students and engineers and added to their repertoire of engineering education activities.

Table 4: Engineering students reflecting on the experience.

Quotes
– “The design experience went beyond my expectations. It fully immersed me in all phases of the design cycle and allowed me to iterate alternate designs multiple times.”
– “[The experience was] Very important, it taught me how to work under deadlines when we actually have something to implement, rather than an arbitrary deadline just because something is due.”
– “I felt this project gave me more experience working with stakeholders outside of group members and classroom faculty.”
– “It gave me the opportunity to collaborate as a group and create something from scratch, much like what engineers do in the field.”
– “I think we all felt vested in the design experience not just for the class, but also to produce a great and worthwhile exhibit at the [science center].”
– “We were able to use creativity in analyzing a topic and developed our effective solution to solve the problem. Thinking like this will help prepare us for the thinking that engineers do.”
– “It allowed me to know that sometimes I have to consistently change my plan in order to improve customer satisfaction.”

In terms of skills, students from both collaborations mentioned gaining engineering skills, particularly professional skills. Two students from Engineer the World explicitly stated that they were prepared for what engineers do, five mentioned engineering skills, and four mentioned professional skills (e.g., collaboration, communication, teamwork, flexibility). Three students from Sound Engineering mentioned collaboration in a multidisciplinary team with people from outside the class, two mentioned engaging in the design cycle, and one mentioned time management.

Not surprisingly, we also see that in the self-rating questions on the post-surveys (Figure 1), the students generally rated their gains higher than the engineers from industry. Students rated that the experience improved their communication skills, confidence in engineering, and understanding of engineering. All five students from Sound Engineering rated a 5 on the 1-5 Likert scale, strongly agreeing that the experience had shown them that they could make a difference as an engineer. The Engineer the World students also rated this highly at an average of 4.4. The average responses for both the students and engineers were highest for making a difference as an engineer and increasing their awareness of community needs. These are particularly valuable because of the relatively low emphasis on ethics and social responsibility in engineering curricula,[38] and indicate that engaging in and reflecting on such real-world learning experiences can help increase engineers' understanding of their impact on the public and world, recognizing that the products and services they create should engage the users in mutual learning experiences in which the user and engineer both learn and contribute.

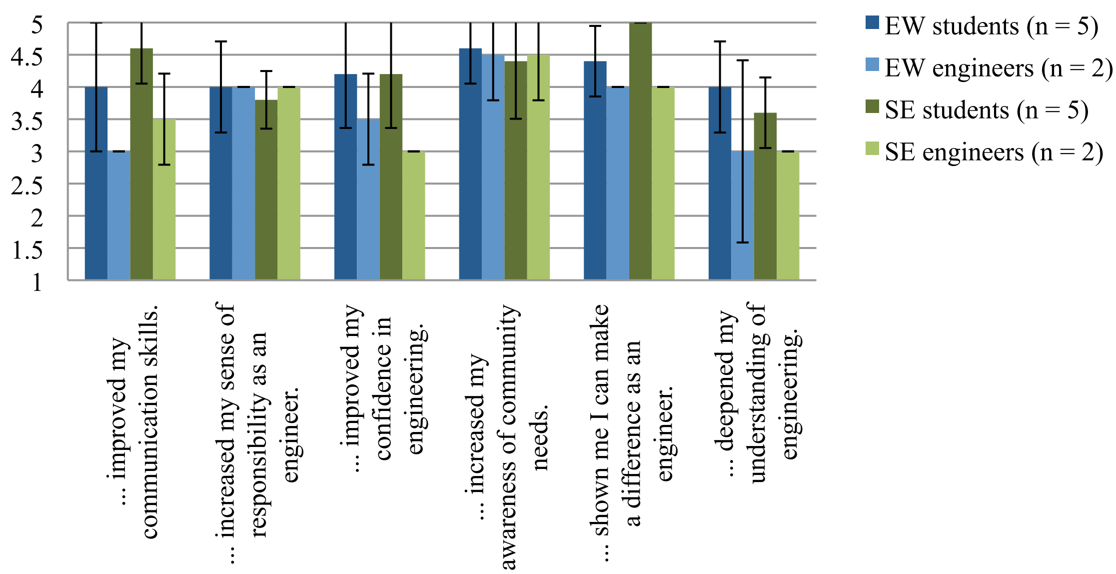

Figure 1: Post-survey self-ratings on the collaboration experience (1-5 Likert scale, with 5 as strongest agreement and 1 as strongest disagreement). EW = Engineer the World and SE = Sound Engineering. (See Table 6 in the Appendix for the full text of the questions.)

Thus, both the actual implementation with the public and the connections with practicing engineers from industry were valued by the students. These kinds of connections can be motivating[39] and appear to strongly motivate the students in these two collaborations. The frequent mention of the rewarding experience outside of their university with the public and the explicit statements about the preparation for professional engineering practice confirms previous research on the benefits of such external experiences,[15,25,40] and further indicate an increased understanding of their actual impact on the world.

Discussion

The multidisciplinary make-up of the collaborations allowed the various members to contribute their own expertise to the design processes. The educators focused on logistics and learning accessibility. The engineering students and the engineers from industry, taking on the bulk of the creative work and engineering tasks, contributed engineering authenticity. The collaborators were flexible in these various roles and accommodated contributions from all members. The educators pushed deadlines and industry engineers pushed for more specification on criteria, all while working flexibly around each other's tight schedules and course timelines and consequently engaging the student teams in real engineering practices for an authentic learning experience. Furthermore, as in authentic engineering practice, flexibility was needed to prioritize criteria, as the constraints of the design situation (mostly logistical) meant that some criteria were excluded and others were implied in the situation.

Because criteria and goals were agreed upon early in the design process, both collaborations established collective ownership of goals, contributing to a smooth ideation process. The student teams constantly reflected on the criteria in selecting and refining their ideas, and with agreement on the criteria, almost zero disagreement played out as they flexibly incorporated feedback from the engineers, educators, and visitors at the science center. Instead, both teams interestingly decided to combine their top two ideas for the final design challenge in order to ensure everyone's contributions were acknowledged and implemented.

While there were many similarities between the two collaborations, differences included the role of the industry engineers, the context of the student participation, and the unique criteria for the challenges. The Engineer the World students were younger and much less vocal in meetings; they were also participating voluntarily rather than as part of a course. Instead, as part of the education outreach club, these students were much more focused on education and teaching while the Sound Engineering students focused much more on the design process emphasized by their course. Thus, the Engineer the World students were more heavily guided by other collaboration members, and the collaboration's engineers contributed more directly to the final challenge than did Sound Engineering's engineers. The educators and engineers heavily guided the criteria development process, and the collaboration ended up with a very broad set of criteria with the goal to show the public what engineering is and that "engineering is for everyone." The Engineer the World collaboration consequently focused on the authentic design-build-test process and engineering as involving creativity for accessibility. On the other hand, the Sound Engineering students were all junior and senior students and selected this collaboration for their course project; these students independently conducted much of the design work as part of their course requirements, but also had greater initiative and confidence than the other students. Thus, these students came up with their own criteria and asked for feedback from the engineers and educators; their explicit criteria were much narrower, but there were many implicit criteria that resurfaced throughout the design process and overlapped with the other collaboration's criteria. They focused on the engineering learning experience as being hands-on and interactive through physical recycled materials and accessible through modularization of design components. This collaboration also uniquely emphasized sustainability from their course lectures. Overall, the two collaborations' combined explicit and implicit criteria overlapped quite a bit, as both aimed to achieve accessibility and authenticity.

Beliefs About Learning

Accessibility and authenticity were thus emphasized throughout the design processes and were achieved through such criteria as personalization, creativity, and facilitation, importantly acknowledging learning as a mutual experience. Many of these criteria emerged through the human-centered design process, in which the collaborations engaged in-situ with the public in the science center context in order to understand their needs. Thus, this human-centered process guided the collaborations towards accessibility and authenticity. For example, the evolution of Sound Engineering's mission statement reflects their changing perception as they engaged with visitors; the statement evolved from portraying learning as passive to active and inclusive. This perception of learning is further corroborated by the collaborators' survey responses. In describing what should be learned and what was learned in the design challenges, both collaborations emphasized accessibility, especially through facilitation and guidance to personalize the experience. Therefore, contrary to some scientists' and engineers' perception of communication of knowledge as one-way,[4-6] these collaborations grew to acknowledge such learning experiences as mutual, with contributions and interactions from learners.

Beliefs About Engineering

An interesting finding emerged from the students' and practitioners' beliefs about engineering. There was no substantial change in their beliefs from the pre- to post-surveys; but, both collaborations emphasized the entire engineering process, societal impact, and creativity, rather than technical knowledge and intellectual ability as key to engineering. This consistency across the members is interesting given the variety of experiences of the members; the Engineer the World students were all sophomore-year students, the Sound Engineering students were all junior- and senior-year students, and the industry engineers' professional experiences ranged from one year to 17 years. Furthermore, when asked about attributes of good engineers, the engineering students and practitioners much more frequently cited hardworking, determination, curiosity, willingness to learn, and creativity than technical math and science ability, consistent with previous findings on engineers' self-perceptions.[41] No engineers from industry named technical ability, and two of the engineers even noted that their weaknesses were specific technical abilities. Thus, these perceptions about engineering align with Dweck's theories of malleable intelligence and growth mindset[35] and underscore the need to change the public perception of engineering to show its accessibility. The National Academy of Engineering's Changing the Conversation report has emphasized attracting new engineers by showing engineering as a creative endeavor and one that helps society;[41] however, the findings here suggest that it is also important to emphasize that engineering is accessible to all through hard work, determination, and curiosity and is not a "hard" unknown that the public may perceive.[36,37] Both collaborations noted in particular that the visitors engaging in their challenge did find engineering accessible, and many children even persisted through many failed attempts and iterations to the surprise of their parents, ultimately finding the experience very rewarding in achieving something that "works."[3] Thus, such collaborations as these may open the way to attract diverse future engineers through persistence and curiosity.

Reflections

Both collaborations reflected on their process and experience, as posited by Schön in the Reflective Practitioner as being vital to professional creativity.[42] Reflections on the process included personal observations and group discussions about the challenge, important for improving the challenge during implementation with the public. Reflections in post-surveys show that the collaboration participants, especially the students, were able to understand the importance of engineering in society and its impact on the world. They valued the experience, and particularly valued the opportunity to contribute substantially to a real challenge that was implemented with the public, noting their personal increase in professional skills and real-world experience. The consequential task also held the students responsible and accountable, and they remarked the value of working with various people and stakeholders, especially with those from outside their classroom.

Through the collaborative design experience, these students engaged in authentic engineering design, working flexibly on a team and reflecting on the process to achieve and prioritize criteria within the constraints of their situation. The human-centered design process allowed the team to dig in and understand the needs of all stakeholders, especially the visitors. Engaging in design as a learning process[30,43] allowed the students to not only learn from the authentic experience, but also from the industry engineers, educators, and visitors.

Self-Selection: Limitations and Opportunities

The collaborators in this study were all self-selected; thus, the pre-post-results might have shown greater differences if the members were randomly selected. However, we do note that many of the students who self-selected had previous engagement with the science center program and consequently chose to return and deepen their experience: three of the students from Engineer the World had previously volunteered with the science center program and three of the students from Sound Engineering had participated as a requirement for a prior course. Because of the self-selection and possibly because of prior experience, these students and the engineers from industry possess desirable values and characteristics of people who engage, which may have resulted in the minimal change between pre- and post-surveys. Thus, the findings from this study uncover the types of engineers that seek to engage in these types of activities and that appreciate different values from diverse team members, traits that are representative of successful professional engineers; these are the types of engineers that the education system should foster. The involvement of these engineers in K-12 learning helps to portray a positive perception of engineering to the public. Experiences like the cross-community collaborations in this study may further foster these types of engineers by engaging other students and the public who would otherwise not be engaged.

Conclusions and Implications

The cross-community design process presents a novel and sustainable way to incorporate real-world engineering with making. The multidisciplinary members of the design collaborations developed newly created activities that incorporated educational accessibility from the educators and engineering authenticity from the engineering students and practitioners. The collaborations developed implicit and explicit criteria that guided the design of their tinkering challenges to engage visitors in a mutual learning experience, rather than a one-way communication.[4-6] The process of identifying criteria also helped to create collective ownership of goals[16] that fostered a smooth and risk-free ideation process, as the final ideas were selected and refined flexibly with the agreed-upon criteria. The designers – both the engineers and students – reflected on how they enjoyed the experience. An engineer stated: "It was nice to see our impact in the field of education." One graduating student said: "It was one of my most valuable experiences in my undergraduate engineering career."

The findings on the engineering students' and practitioners' beliefs about learning and engineering and their reflections provide implications for engineering education. Following a human-centered design approach, the students and educators first observed similar activities at other museums and worked with the industry sponsors, consequently identifying key features of the design challenge that would otherwise have been overlooked. As a consequence of the collaboration, the engineering students and practitioners identified the social implications of their engineering roles. A key takeaway is that in designing these learning activities, it is important to involve the engineers with the users in-situ to help develop important criteria that serve to create products and services that engage the users in mutual learning experiences in which the user and engineer both learn and contribute.

Another implication comes from the engineering students' and practitioners' awareness that engineering involves much more than technical skills or intellectual ability, contrary to popular public conceptions of engineering.[36,37] In the surveys, students and engineers noted that the attributes of good engineers were mostly non-technical, including hardworking, determination, curiosity, willingness to learn, and creativity. As Dweck has shown, the malleable intelligence and growth mindset is important for many subject areas;[35] however, it is of particular importance in engineering, which the public commonly perceives as hard and inaccessible,[36,37] potentially contributing to the low numbers of aspiring engineers. In order to help change the negative perception of engineering, it is therefore important to not only show what engineering really entails – creativity and benefitting society[41] – but also to show that through hard work, determination, and willingness to learn, engineering is accessible to all and is rewarding. Broader and general community STEM outreach should work to portray engineering as such. Future research should explore this finding more in depth, implementing cross-sectional longitudinal studies to determine if the finding on the perception of engineering is consistent and whether fostering a malleable mindset[35] can improve engagement in and perceptions of engineering.

Finally, the differences between the two collaborations suggest that embedding the project within a course may have driven the students to take more ownership over the design process, as in the Sound Engineering collaboration. The students were especially excited to have authentic components in a course project, in particular, the authentic stakeholders through the industry engineers and the Lawrence Hall of Science and the authentic implementation of the final design challenge with the public. They noted that they felt they learned more from their project than they could from the other course projects that were not implemented. Other engineering courses can build off of this service learning approach; large-scale implementation for a large course may be achieved with the recruitment of multiple industry sponsors for the student teams such that each team can work to develop engineering design activities representing each sponsor. These final design activities could not only be implemented in a science center, but could also be implemented in local schools.

Through the collaborative design process, the co-design collaborations deconstructed their engineering practices to engage visitors in accessible and authentic learning experiences to construct their own engineering practices. By engaging practicing engineers and engineering students in not only the implementation, but the *design* of the activities, the collaboration benefitted (1) the visitors by engaging them in mutual learning experiences through broader and rewarding engineering design practices, (2) the students by providing experience in authentic, consequential projects,[44] (3) the engineers and their organizations by increasing morale and portraying their impact through corporate social responsibility,[11] and (4) the educators at the science center by providing content and much-needed resources.[7]

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Appendix A: Pre- and post- surveys for collaboration members.

Table 5: Pre- and post- survey open-ended questions given to the collaboration members, including the engineering students, industry engineers, and informal educators.

Pre	Post
	What was valuable about this Ingenuity Lab collaboration design experience?
What do you hope to contribute?	How did you contribute to the challenge design?
What do you hope to get out of this project?	Did the collaboration design experience meet your expectations? Why or why not?
How do you define engineering?	How do you define engineering? How do you think your challenge teaches engineering?
What are attributes and characteristics of a good engineer?	What characteristics and attributes define a good engineer?
What are your strengths and weaknesses as an engineer?	What are your strengths and weaknesses as an engineer?
Please list your criteria for a good engineering learning activity.	Please list your criteria for a good engineering learning activity.
What about engineering do you think engineers should teach to visitors (children and adults) who aren't familiar with engineering?	What do you think visitors have learned from your challenge?
	Describe a typical successful interaction at your Ingenuity Lab challenge. What methods have you found to be most effective in engaging with visitors?
	What have you found most interesting about how visitors engage with your challenge?
	What are the key elements to your Ingenuity Lab challenge?
Briefly describe your engineering experiences.	
Why did you decide to be an engineer?	
	How could this collaboration experience be improved?
Any other comments/questions?	Any other comments?

Table 6: Post-survey Likert questions, ranking from 1-5 from disagree to agree, given to collaboration members.

Please indicate your agreement with the following statements. This experience has ...
... improved my communication skills.
... increased my sense of responsibility as an engineer.
... improved my confidence in engineering.
... increased my awareness of community needs.
... shown me I can make a difference as an engineer.
... deepened my understanding of engineering.

Appendix B: Recruitment document for Engineer the World student collaborators.

Design an Ingenuity Lab challenge for the Lawrence Hall of Science with Google Engineers!

Overview
The Lawrence Hall of Science (the Hall) is a public science center part of the University of California, Berkeley. Located in the Berkeley Hills above the campus, the Hall provides hands-on science, math, and engineering exhibits and programs, serving mostly school groups on weekdays and family groups on weekends, with ages ranging from infant to elderly. The majority of children are between the ages of three and twelve. This project focuses on the *Ingenuity Lab*, an engineering design program open to drop-in visitors from 12-4pm on weekends.

The *Ingenuity Lab* began in Fall 2009, providing open-ended tinkering programming to visitors. The lab itself is held in a large classroom space, allowing visitors to come and go as they wish. Each month, an engineering design challenge and theme is presented to visitors, along with appropriate materials (low-cost consumables and/or reusable electronics). Visitors design, build, and test solutions to the challenges. Past challenges have included LEGO robotics, where visitors use LEGOs, PicoCricket microcontrollers, sensors, motors, gears, and wheels to design their own robotic cars; mechanical grabbers, where visitors use sticks, rubber bands, wires, tubes, string, and sponges to create grabbers to pick up objects; scribble machines, where visitors use motors, batteries, glue sticks, cardboard, tubes, and markers to make vibrating machines that draw patterns; cardboard automata, where visitors use cardboard, foam, string, sticks, and paper to develop mechanical sculptures; and boats, where visitors use paper, pennies, foil, tape, balsa wood, and string to design boats that float and sail.

Interested students will help extend the current program at the *Ingenuity Lab* in a collaboration with Google engineers and museum educators by designing and developing an engineering design challenge. The challenge, representative of the engineering work at Google, will serve as November's monthly theme for the *Ingenuity Lab*. The commitment will last from September to November, about 20 hours in total. The hours consist of four meetings (three of which will be at the Hall) along with individual and team work outside the meetings. All of your work should be documented in a notebook dedicated to this project.

See the following links for more details and examples of past challenges:
http://lawrencehallofscience.org/visit/activities/ingenuity_lab
http://www.flickr.com/photos/lhsingenuitylab

Schedule outline
Sunday, September 16, 11am-3pm: 1^{st} meeting
Orientation and training, initial group brainstorm with Google engineers
Outside work: Brainstorm more ideas individually before 2^{nd} meeting
Tuesday, September 18, 9-10pm: 2^{nd} meeting
Brainstorm more, select top 2-3 ideas
Outside work: Design, build, and test prototypes for top ideas before 3^{rd} meeting
Date TBD, October 4-10, 1 hour: 3^{rd} meeting
Select final idea and get feedback on prototype
Outside work, October: Refine prototype and ready for implementation by November
Outside work, November: Implement and facilitate in the lab (split up weekend facilitation among team)
Get feedback on implementation, refine implementation
Prepare oral presentation and short write-up (1-2 pages)
Sunday, November 18, 1 hour: 4^{th} meeting
Present final idea & challenge through oral presentation and short write-up

If you have any questions, please contact Jennifer Wang at

Appendix C: Recruitment document for Sound Engineering student collaborators.

Engaging families in Meyer Sound engineering at the Lawrence Hall of Science

Background

The Lawrence Hall of Science (the Hall) is a public science center part of the University of California, Berkeley. In 2009, the Ingenuity Lab was created as a space for families to design, build, and test solutions to open-ended engineering challenges using assorted low-cost materials and reusable electronics. Challenges change each month, and past challenges have included *LEGO robotics*, where visitors use LEGOs, PicoCricket microcontrollers, sensors, motors, gears, and wheels to design their own robotic cars; *mechanical grabbers*, where visitors use sticks, rubber bands, wires, tubes, string, and sponges to create grabbers to pick up objects; and *scribble machines*, where visitors use motors, batteries, glue sticks, cardboard, tubes, and markers to make vibrating machines that draw patterns. See http://www.flickr.com/photos/lhsingenuitylab/sets/ for photos of the lab in action and the website at http://lawrencehallofscience.org/visit/activities/ingenuity_lab.

Award winning Meyer Sound develops audio engineering solutions and equipment, most notably loudspeakers and sound systems, for live sound reinforcement and recording. Meyer Sound products are manufactured entirely at its Berkeley factory, where high technology is combined with hand craftwork. Meyer Sound has provided solutions for venues and performances all over the world, such as Memorial Stadium, Zellerbach Hall, Comal Restaurant in Berkeley, Lollapalooza, the Nobel Peace Prize Concert, the Dalai Lama, MythBusters, and Cirque du Soleil tours and other shows in Las Vegas.

Problem Description

Families do not necessarily have a good understanding of engineering, and even at the Ingenuity Lab, oftentimes can't make the connection of the challenges to real engineering. The Hall is interested in developing an engineering design challenge for families to engage in sound engineering representative of Meyer Sound engineers' work. The Hall and Meyer Sound would like to sponsor a student design team to conduct user studies with families and background research on Meyer Sound engineering to design, refine, and implement the challenge to be offered to the public for the month of April. The Hall will provide a budget for prototyping materials and all materials required for the month of the challenge. The open-ended challenge should

- Engage families of all backgrounds, ages, and genders;
- Encourage collaboration and spreading of ideas;
- Allow for short iterations and small improvements on solutions from within 20 minutes to over an hour; and
- Have a non-subjective test to determine how well the engineered solutions achieve the goal.

The project will involve working with Meyer Sound engineers and Hall educators to collaborate on a challenge that satisfies these clients' needs. Student teams will be actively involved in the implementation of the challenge in April.

Possible Solution Strategies

New Product Development teams may want to address some or all of the approaches below:

1. Analyze current visitor trends at the Ingenuity Lab and features of the current challenges
2. Conduct user studies to identify what attracts and sustains visitors, at the Hall and other science centers
3. Research engineering content using resources such as sound engineering textbooks and papers, Meyer Sound engineers, and a tour of the Meyer Sound facilities
4. Research effective curriculum in the learning sciences, especially in informal learning environments
5. Compare the economic costs and visitor impact of using expensive special equipment to be reused versus cheap consumable materials that visitors can take home
6. Devise methods to extend the learning experience beyond the museum, such as creating effective hand-outs for visitors to learn more about the engineering and to continue similar activities at home
7. Develop and implement conceptual designs of the most effective Ingenuity Lab layout for the challenge
8. Assess any increase in visitor attendance, membership sign-ups, and/or stay-time generated from the Meyer Sound challenge in April
9. Determine what visitors learned and enjoyed from the challenge, as well as possible improvements for the challenge and future challenges

Contact Details:
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354 Hearst Memorial Mining Building

THE LAWRENCE HALL OF SCIENCE
UNIVERSITY OF CALIFORNIA, BERKELEY

thinking sound Meyer Sound

Appendix D: Recruitment document for industry engineers.

THE LAWRENCE
HALL OF SCIENCE
UNIVERSITY OF CALIFORNIA, BERKELEY

Ingenuity Lab Corporate Partnership

Project summary

Volunteer engineers will collaborate with UC Berkeley engineering students and the Hall's museum educators to help develop a design challenge that is representative of what your company's engineers do and accessible to children. The design challenge will be a monthly theme for the Ingenuity Lab, a space for families to design, build, and test solutions to open-ended engineering challenges using assorted low-cost materials and reusable electronics. See http://www.flickr.com/photos/lhsingenuitylab/sets/ to view photos of the lab in action and the lab website at http://lawrencehallofscience.org/visit/activities/ingenuity_lab.

Volunteer tasks

- Serve as advisors and mentors to the challenge development team, mostly UCB engineering students
- Provide engineering expertise to the project
- Offer feedback and input to the challenge development process
- Ensure that the final design challenge presented to the public is representative of engineering work at your company

Time commitment: ~10 hours over 4 months

- 1 half day (4 hours; at the Hall) for introduction and initial brainstorm
- 1-hour (remote) meeting to select top challenges to prototype
- 1-hour (remote) meeting to provide feedback on prototype testing and to select final challenge
- 1 half day (4 hours; at UCB/the Hall) to attend final team presentation and see the challenge implemented at the Ingenuity Lab

Who can get involved?

- 1-5 engineers
- Any others interested can be involved at a lower level than described above, mostly providing input and feedback when they are able to

Benefits of participating

- Contribute to this novel approach for the Hall to incorporate local, community engineering into programming to expose the public to real engineering
- Opportunity to not only show or tell visitors and the Bay Area public what your company does, but involve visitors in hands-on engineering of your company
- Inspire families to pursue engineering activities and consider engineering as a potential career
- Work with UCB engineering students, potential recruits, exposing them to your company and the type of work done at your company
- Marketing and visibility through branding on the challenge in the Ingenuity Lab space, on the website, and other marketing materials before and during the month of the challenge