Cross-Community Design and Implementation of Engineering Tinkering Activities at a Science Center

Jennifer Wang
University of California, Berkeley
354 Hearst Memorial Mining Building
Berkeley, CA 94720-1764
+ 1 510 642-1191
jennifer_wang@berkeley.edu

Alice M. Agogino
University of California, Berkeley
415 Sutardja Dai Hall
Berkeley, CA 94720-1764
+1 510 642-6450
agogino@berkeley.edu

ABSTRACT
This paper details the design and implementation of two activities for a science center's drop-in engineering tinkering program. The novel aspect of this study is the engagement of two cross-community teams of industry engineers, engineering college students, and educators to co-design the educational activities. We analyze the teams' experiences and the activities' impact on learners' "engineering-as-tinkering" experience. In deconstructing engineering practices, the design teams negotiated explicit and implicit criteria for the activities, with the implicit criteria emphasizing visitor perspectives that molded the activities into mutual learning experiences. The teams valued the authentic and consequential impact on the public. Visitors are found to engage in engineering behaviors similar to experts, discussing the relation to the real world and constructing their own practice of engineering with problem scoping, planning, and evaluation.

Categories and Subject Descriptors
K.3.0 [**Computers and Education**]: General

General Terms
Design.

Keywords
Museums, informal learning, engineering, tinkering, making, design challenges, collaboration, corporate social responsibility.

1. INTRODUCTION
Science centers offer alternative learning environments that can play key roles in dispelling the perception of engineering as "hard" or "not for me" and thus increase broader participation in engineering. Opportunities for engaging in engineering should be presented early on; many engineers attribute their careers to early interest in STEM [25]. Interest, not performance, has been shown to be a greater predictor of choosing to concentrate in STEM [17,25]. A popular STEM activity is tinkering and making, and following the Maker Movement, science centers are increasingly implementing these types of programs.

To understand how to communicate and engage science center visitors in authentic engineering, we study a unique collaboration involving engineers and engineering students in the design of

educational tinkering activities. The impact of these scientist-educator collaborations on learners has been found to be positive [e.g. 16,26]. However, we research not just the learners, but also the engineers and engineering students as co-designers.

Past studies have explored how scientists have viewed their role in outreach as one-way communication, in which they transmit important knowledge to learners with minimal contribution from or personalization for learners [7,12,18]. In this study, with the unique context of open-ended and self-driven tinkering and the teams' role in the *design* of the activities, does the one-way communication perception hold true? To explore this, we seek to understand the cross-community designers' processes to deconstruct their engineering practices for visitors and whether the perception is reflected in their criteria for a "good" engineering tinkering activity. And, we seek to understand the impact on visitors' engineering design processes in order to confirm previous positive findings [16,26].

2. LITERATURE REVIEW
2.1 Learning in Informal Environments
Informal environments are distinct from classrooms because they offer free-choice learning [11]. Science center visitors choose which activities to participate in and can leave at any time. Furthermore, visitors tend to visit in groups with varying backgrounds. Parents come to science centers with children to spend time together, have fun, and learn [19]. Thus, science centers must attract and retain diverse visitors.

In order to stay relevant, science centers strive to offer content with current science and engineering [13] and can do so through collaborations with professional scientists and engineers. However, despite the support for scientist-educator collaborations [e.g. 12,13,24], such collaborations are often difficult because of the scarce resources required to keep these non-profits constantly updated [13], a negative peer professional image of scientists and engineers who take time out to help these educational programs [21], and the challenge to convey professionals' practices as accessible and understandable to a quickly passing visitor [7]. The further engagement of professionals *and* students provides an avenue that overcomes some of these obstacles by providing a service learning project for students to undertake substantially.

2.2 Making and Tinkering: Engineering Design
The Maker Faire Report describes making as "tinkering, hacking, creating and reusing materials and technology" [20]. Making encourages safe experimentation; learners make mistakes but retain their confidence and identity to pursue their interests. The renewed interest in DIY projects [15] has provoked questions of how these projects can be educational [20]. The constructionist

perspective is to view these projects as design; Papert [22], Resnick [23], and Bamberger [3] emphasize the process of constructing entities as the driver of meaningful learning. Dym et al. [8] state "design is both a mechanism for learning and in itself a learning process." Design is particularly effective in education because it fosters ownership [6] and is accessible to many types of learners [4,22,23]. Open-ended design activities give learners responsibility for structuring their own activities [9] and creating their own artifacts through various paths [22]. Consequently, as a mutual learning experience, design can foster more meaningful experiences than other types of activities. This study specifically evaluates learners' engineering processes in these activities.

2.3 Expert Engineering Design Processes

To determine the engineering design processes of the visitors, this paper draws from Atman et al. [1,2], in which the authors compare design processes of students and expert engineers. Participants engaged in open-ended problem-solving to design playgrounds. The authors developed design process timelines, noting frequency of transitions between activities, duration of activities, and solution quality. They found that when compared to students, experts spent more time on the problem overall, especially in problem scoping. Experts also gathered more information and iterated between activities. Most importantly, experts' design processes portrayed a cascade pattern that progressed from *Problem Scoping* to *Developing Alternative Solutions* to *Project Realization* (Table 2).

3. BACKGROUND

3.1 The Ingenuity Lab

The Ingenuity Lab at the Lawrence Hall of Science provides open-ended tinkering design challenges to drop-in visitors [27]. The majority of children who visit are between ages three and twelve. The program is held in a large classroom space, 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.

3.2 The Cross-Community Design

This study builds on the current program by developing and implementing a cross-community collaboration model with industry engineers, engineering students, and informal educators to develop open-ended engineering design challenges. Two new challenges, representative of the engineering work of two companies, a local software engineering company and an audio engineering company, are designed and implemented with visitors in the Ingenuity Lab (Table 1).

4. METHODS

The design teams were ethnographically studied through pre-/post-surveys, observations via video-recording, and artifacts, including notebooks, write-ups, and presentations. Observation and pre-/post-interview data were collected for visitors at the two activities. Observations were video-recorded with field notes.

The design team analysis focuses on the criteria development for the activities as well as post-survey reflections. Criteria for the activities were thematically extracted from all data in an emergent analysis. The visitor analysis focuses on video observation data. Video data were segmented into engineering design behaviors

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.	

(Table 2). Two researchers coded videos, overlapping on one from each challenge representing a typical interaction. The researchers met weekly to ensure consistency. Percentage agreement between the coders was 90%. The behaviors were adapted from the Elementary is Engineering Design Process [10] and refined through the coding process. Drawing from Atman et al. [1,2], timelines highlighting behaviors were developed.

4.1 Participants

4.1.1 Design Teams

The first team that created Engineer the World consisted of two engineers from the software engineering company, five sophomore-year engineering students, and an educator. The students participated voluntarily through an engineering education outreach club and for course credit during Fall 2012.

The second team creating the Sound Engineering challenge consisted of an engineer and technical support specialist from the audio engineering company, five junior/senior-year engineering students, and an educator. The students worked on the challenge for a product design course project during Spring 2013.

4.1.2 Visitors

Over 611 visitors participated in Engineer the World in November 2012 and over 886 visitors participated in Sound Engineering in April 2013. Twenty-six groups from each challenge responded to surveys. Three sets of observations and interviews were conducted at Engineer the World, each with two participants, totaling six participants. Five sets of observations and interviews were conducted at Sound Engineering, each with 1-3 participants, totaling ten participants. Ages for participants ranged from 3-13.

5. FINDINGS

5.1 Design Teams

Analysis of the data demonstrates that two sets of criteria were formed to achieve the teams' missions – an implicit set and an explicit set. The explicit set emerged when the team explicitly listed the project's needs, while the implicit set came about informally through conversations and personal notes.

Table 2. Engineering design behaviors coded in videos with examples and as related to design activities [1,2,5]: *Problem Scoping* **[Identification of Need (ID), Problem Definition (PD), Information Gathering (GATH)];** *Developing Alternative Solutions* **[Generation of Ideas (GEN), Modeling (MOD), Feasibility of Analysis (FEAS), Evaluation (EVAL)]; and** *Project Realization* **[Decision (DEC), Communication (COM), Implementation (IMP)].**

Engineering Design Behavior	Example	Design Activity
1. Describes/identifies a problem to be solved	*"How do you connect this [the gears] so that the wheels go?"*	ID / PD
2. Expresses a design goal	*"I wanna make it really low."*	ID
3. Considers one or more options for achieving goal	*"So we'll probably have to tape this, or paper clip."*	GATH / GEN
4. Sketches design	Draws design on paper.	MOD
5. Explores/selects appropriate materials/tools from options	*"[This] has 10 times as many. Which one do you want to use?"*	GATH / MOD
6. Makes causal inference/predictions on how design will perform	*"If it's lighter, will it go faster?"*	MOD
7. Builds or modifies design	Building or modifying object with a purpose	IMP
8. Tests design	Tries design with test.	FEAS
9. Analyzes what happens and what can be improved from the tests	*"Oh look, it kinda slows it down, huh?"*	EVAL
10. Discusses how this activity relates to the real world, engineers, …	*"Just like that guitar. Strings, they like to break."*	GATH / EVAL
11. Looks at/compares with other designs	*"See, mom, look at this one. This chain over here doesn't fall off."*	GEN / GATH / EVAL

Explicit criteria focused on goals of the activity for all: visitors, engineers, and the Lawrence Hall of Science. For example, the sound team's explicit criteria included fun and informative, goal-oriented, iterative design, allow for creativity, and sustainable.

Implicit criteria were almost exclusively focused on the visitor experience. These represent understanding of the learning process as a two-way, rather than a one-way, experience [7,12,18] in reflecting visitor needs and backgrounds. These criteria came from participating in and observing the Ingenuity Lab, as well as interviews with visitors. For example, the sound team implied criteria for guidance, accessibility, attractiveness, and challenge.

Thus, in order to translate their implicit engineering practices to explicit practices for visitors, the teams negotiated a play between explicit and implicit criteria. Not all criteria were explicit, and

Table 3. Student designers 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."
"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 LHS."

notably criteria acknowledging the two-way experience were mostly implied, many of which took precedence over the explicit criteria. Therefore, in designing these activities, designers should engage with learners in-situ to develop important implicit criteria.

In post-surveys, the engineering students cited increased understanding of design processes and the greater real-world relevance (Table 3). The engineers were able to reach out to the public and teach them about their field. Finally, the educators were able to add authentic engineering to learning activities that included the ability to understand user needs, design, prototype, test, and redesign.

5.2 Visitors

The teams' criteria informed the development of the challenges; as the outcome of the teams' efforts, visitors engaged in engineering practices in these tinkering design challenges.

When compared to visitor timelines in other challenges not developed through cross-community design [28], visitors at these two activities engaged more in behaviors 2-4, 6, and 9-11 (Table 2). Thus, these visitors engaged in more problem scoping, planning, and evaluation as opposed to mostly building and testing; they also discussed the real-world relevance much more.

In terms of their design processes, all Engineer the World timelines (Figure 1) demonstrate a cascade pattern. Participants at this challenge exhibited *Sketches design*; however, none return to it after implementing their website on the computer. Half of participants looked at other prototype and real websites. All groups discussed the activity's real world relation.

Sound Engineering timelines (Figure 1) all show a cascade pattern. Visitors here spent most time in *Explores/selects appropriate materials/tools*, *Builds or modifies design*, and *Tests design* (Table 2). They exhibited *Analyzes what happens and what can be improved* consistently after tests. All groups looked at other designs and three discussed the relation to the real world.

6. CONCLUSION

The cross-community design process presents a novel and sustainable way to incorporate real-world engineering with making. The design teams 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 [7,12,18]. As a consequence, the design teams

Figure 2. Sample visitor design process timelines for Engineer the World (top) and Sound Engineering (bottom).

deconstructed their engineering practices in order for visitors to construct their own engineering practices. Visitors' design processes portray cascade patterns, indicating that visitors are not just playing, but engaging in engineering like experts. The cross-community design correlates with increases in visitors' awareness of the real-world relevance and increases in their engagement in broader engineering behaviors, not just building and testing. 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."

By engaging 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 engineering design practices, (2) the students by providing experience in authentic, consequential projects [6], (3) the engineers and their organizations by increasing morale and portraying their impact through corporate social responsibility [14], and (4) the educators and the science center by providing content and much-needed resources [13].

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