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What Do Young Makers Learn?

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Dr. Jordan also founded and led teams to two collegiate National Rube Goldberg Machine Contest championships, and has co-developed the STEAM Labs™ program to engage middle and high school students in learning science, technology, engineering, arts, and math concepts through designing and building chain reaction machines. He has appeared on many TV shows (including Modern Marvels on The History Channel and Jimmy Kimmel Live on ABC) and a movie with his Rube Goldberg machines, and worked as a behind-the scenes engineer for season 3 of the PBS engineering design reality TV show, Design Squad. He also held the Guinness World Record for the largest number of steps – 125 – in a working Rube Goldberg machine.

What Do Young Makers Learn?

Introduction

The purpose of this NSF-funded study "Might Young Makers Be the Engineers of the Future?" is to understand Young Makers in K-12 and how their knowledge, skills, and attitudes might prepare them to pursue advanced STEM education and careers. Makers are an emerging community of self-described DIY-enthusiasts, tinkerers and hobbyists. Popularized by the quarterly magazine MAKE and annual Maker Faire events, this work seeks to examine and better understand the context of their activities, particularly in informal engineering education and tinkering activities. Makers embolden characteristics from the Engineer of 2020, and in particular practical ingenuity, creativity, and propensity toward lifelong learning; making is of particular interest to the field of engineering and to engineering educators.

The goal of our study is to understand Young Makers in K-12 and how their knowledge, skills, and attitudes might prepare them to pursue advanced STEM education and careers. The mission of this research is to develop a theory, inductively grounded in data and deductively built on literature, illuminating the knowledge, skills, and attitudes of Young Makers related to pathways forward to engineering and STEM-related majors and careers. By describing their pathways to or around formal engineering education will better inform future innovations in order to improve the practical ingenuity and lifelong learning of our future engineers. The specific research questions to be answered are:

RQ 1. What knowledge, skills, and attitudes do Young Makers possess that could be related to engineering?

RQ 2. How do pathways of Young Makers intersect with engineering?

This study will advance the currently limited knowledge of the Young Maker community by developing theory characterizing Young Makers and their pathways through the lens of formal engineering education. The aim is to establish evidence as to how Makers embody specific attributes of the Engineer of 2020 and discover additional attributes of Young Makers that could define the engineer of the future and effects their pathways to STEM majors and related careers. The results of this study will transform the conversation of who Young Makers could become, linking Making with engineering in the same way that students who excel in science and math are pointed toward engineering by parents and career counselors. By sharing a diverse (by age, gender, and ethnicity) set of success profiles of Young Makers widely in the formal education system to students, K-12 school administrators, university leaders, admissions officers, and to Young Makers both online and at Young Maker community events, we aim to illuminate pathways for Young Makers to become the engineers of the future. In addition, this study could inform future innovation in formal K-12 STEM pedagogy based on successful attributes of informal engineering education and tinkering activities.

Methods

Using qualitative research methods of artifact elicitation and critical incident interviews, we are developing a theory describing Young Makers and their preparation to pursue advanced STEM education and careers. The interview protocols were based on themes that emerged from our related Adult Maker study (EEC-1232772)[1]. After interviewing our first round of participants at the Bay Area Maker Faire in May 2014, we discovered that parents and families were extremely important to supporting Young Makers. We then expanded our interviews to start looking at Maker Families, interviewing children about their experiences Making, parents about how they support their kids in Making and what they think their kids are learning, and siblings (who are often also Makers). The idea of Maker Families is particularly interesting because it aligns with the Family Engineering movement which seeks to broaden participation by encouraging families to engineer together. We are continuing artifact elicitation interviews at Bay Area and World Maker Faires in 2015 and 2016, and conducting follow-up critical incident interviews. Some analysis has begun to support early publishing of conference papers, but we intend to fill out sampling gaps prior to a deeper analysis across all of the participants.

To date, 40 Young Makers and 22 parents have been interviewed at Maker Faire events. We intend to continue interviewing Young Makers at Maker Faire events and through additional channels in the coming year, in addition to continuing transcription and analysis toward our goal of developing a Young Maker theory.

Per our research plan, separate but separate but simultaneous inductive and deductive analysis are underway on the interviews collected at the Bay Area and World Maker Faires to date. Following these analyses, a preliminary theory of Young Makers will be developed, informing theoretical sampling during our data collection expedition to the Bay Area Maker Faire in San Mateo, CA (in May 2016). We hope to finalize our sampling at this Maker Faire.

Maker Theory: Additive Innovation

Findings from our qualitative artifact elicitation and critical incident interviews showed that Makers demonstrate the characteristics of an *Additive Innovation*[2,3] mindset that describes the open community of sharing and learning that is in the Maker community. Introduced in this paper as an umbrella concept, *Additive Innovation* is a mode of collaboration where participants in a community are:

a) inspired by shared artifacts/ideas,
b) openly share (and learn about) technology and processes used to create these, artifacts/ideas,
c) design and prototype own modified version of the shared artifact/idea, and
d) share their modified artifact/idea back with the community.

The community design process in Figure 1 illustrate the mindset of additive innovation.

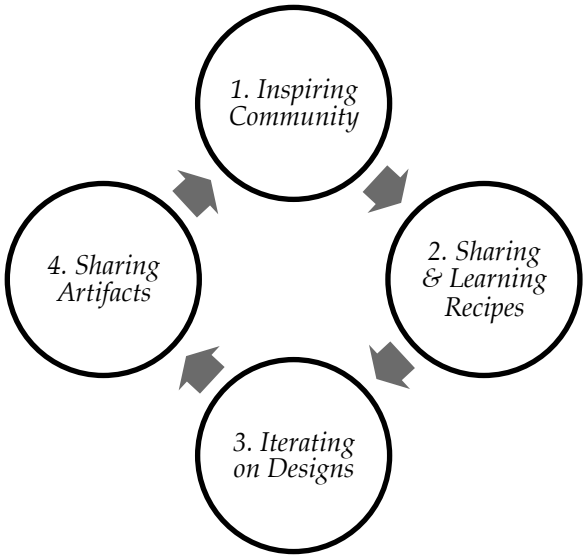

Figure 1. Additive Innovation Mindset Community Design Principles

Current Research Avenues

As our research team continues to analyze and synthesize data collected, avenues for additional research and focus emerge. For work presented here at ASEE 2016, we can summarize the following additional work.

Informal Science and Formal Science Education

Museums and Informal Science Education[4]

Making is becoming a popular activity for young people to get interested in STEM topics. Maker Faire events and extracurricular making clubs support this engagement. Informal science education, particularly through science and technology centers have been adopting making activities for floor programs and some have created maker spaces. This study explores how museums, and in particular children's museums, incorporate making for young makers and families and how educational learning objectives match up with the attributes of making and values expressed by maker families.

This will be addressed by both qualitative analysis of ongoing interviews with Young Makers and the parents of Young Makers. Emergent thematic analysis is be used to highlight themes relevant to Maker families working together. Additionally, this work will explore the goals and practices of informal science education museum community and establish a baseline and range of Making activities and maker spaces in childrens' museums.

There is a trend for museums and science/technology centers to establish Maker spaces. The Pittsburgh Children's Museum has created Makeshop, a maker space reflecting 7 specific learning practices, for example. Research has shown Maker spaces as sources of multidisciplinary learning, a blending of communities of practice with formal learning, and

finally that the depth of learning is in the making. While the research points to the values of Making in general, and specifically making in museum maker spaces, there seems to be little research on family making, and how museums can encourage family making. This research hopes to bridge both these gaps by studying the importance of family making and its relevance in children's museums.

Data has been collected over the last 3 years from the New York and Bay Area flagship Maker Faires with sets of interviews with approximately 32 Young Makers and the parents of Young Makers. The particular perspective of Maker families and the associated analysis has not been previously done and this study will allow for me to explore what it means to be a Maker family. Additionally, I will extend this work to have discussions with museum professionals of their informal STEM learning goals and how the hands-on exploration, tinkering and discovery abound in the Maker community could fit the learning goals. Guidelines and best practices across childrens' museums and will create a taxonomy of varying levels of use of Making activities.

Science Fairs and Maker Faires[5]

Participation in the school-based science fair is ubiquitous to the middle-school student. Rising in popularity is the community based, extracurricular Maker Faire for the young tinkerer or maker. With this study, we share perceptions of these 2 canonical STEM events from the perspective of Young Makers. We report on the perceptions of science fairs and Maker Fairs from the perspective of 35 young Makers ages 7-18, who participated in a flagship Maker Faires in the United States. Using thematic analysis we analyze their responses during qualitative interviews and report on their impressions of their science fairs and Maker Faires experiences.

Both science fairs and Maker Faires present authentic STEM learning opportunities for the K-12 student. They have similar formats where the student presents work that they have done, both the process and end product or result. Opportunities often arise in both to engage and excite a student in an area of curiosity. Both types of fairs want their participants to interact with each other and provide each other with feedback and a learning environment. They also want the participants to well document their projects.

Emerging themes indicate both similarities and differences and how those affect the projects represented in each. Both types of fairs are unique and provide a learning experience for their respective participants. Participating in Maker Faires is, study participants believe, provides more applied learning about science, engineering, and community concepts as compared to their participation in science fairs. Maker Faires may provide an opportunity for schools to promote deeper learning. Additional analysis will explore this further.

An example of a science fair is the Intel International Science and Engineering Fair, around since the 1950s. ISEF materials define science fair as "research [as]… a process by which people discover or create new knowledge about the world in which they live…Students design research projects that provide quantitative data through experimentation followed by analysis and application of that data." Specific learning objectives are learning the scientific method, answering a question, and communicating their research clearly. The science fair also offers an

opportunity for feedback on how their project compares to others in a competitive school setting (with awards at the local, regional and national competition level).

Organizers describe Maker Faire as "part science fair, part county fair, and part something entirely new, …an all-ages gathering of tech enthusiasts, crafters, educators, tinkerers, hobbyists, engineers, science clubs, authors, artists, students, and commercial exhibitors." Maker Faires have become increasingly popular since inception more than 10 years ago, with attendance at flagship Bay Area Maker Faire reaching 130,000 and 85,000 at the flagship New York Maker Faire. Aims are promoting self-motivated learning, give makers a place to freely show of their project, and to be transformation educational experience.

An increasing trend is bringing making activities to K-12 in the classroom, in collaborative maker spaces, and through clubs. This may allow for opportunities to benefit from both science fairs and Maker Faires, including a new initiative to have Maker Faires at schools. We will present implications for STEM and STEAM informal learning and means to engage in STEM, and particularly engineering, in and outside of the science classroom in K-12 education.

Supporting K-12 Student Self-Direction with a Maker Family Ecosystem[6]

Makers are those who use technology to solve problems and invent solutions. The problems are personal in nature to the individual Maker, resulting in passionate, self-directed work towards a solution. With this work, we investigate youth actively participating in the Maker Community and how lifelong learning, or self-direction, is supported by their family ecosystem. As part of the "Engineer of 2020" vision, particular student characteristics directly connected to the activities of Making such as creativity, practical ingenuity and lifelong learning are noted. Such skills and dispositions are hard to identify in young people. From qualitative interviews with these Young Makers and their parents at flagship Maker Faire events, we start to see evidence of roles in the learning ecology. We are interested in understanding these roles, how it may reflect maker family values, and how these values may translate to characteristics of successful K-12 students, and a pathway to interest and majoring in engineering, and engineering careers. Young Makers at flagship Maker Faires demonstrate engineering thinking and doing in abundance. Children as young as 10 are designing, programming, and manufacturing such artifacts as smart watches for their peers. The engagement and excitement is remarkable for their age. A common theme amongst these Young Makers is that they have no formal education in, or knowledge of what is they are actually doing, from their K-12 schooling. And this is what makes it so fascinating. The Maker Mindset has much in common with ABET's student learning outcomes for engineering students but is not rooted in similar standards and expectations at the K-12 level.

Standardization and Accreditation – ABET for Undergraduate Engineering Programs[7]

In this research thread, the skills Makers are learning are categorized according to their fit with existing ABET standards. Makers, both young and adult alike, learn a variety of skills and knowledge to create technically sophisticated artifacts of personal interest in their informal making activities. This paper demonstrates that ¾ of the makers we interviewed are learning how to communicate technical details to a wider audience, half are learning valuable techniques to foster lifelong learning, half are learning how to apply engineering knowledge to solve problems,

and half are learning specific skills applicable to electrical engineering and manufacturing engineering programs. Universities are asked to demonstrate continuous improvement. For many this means opening maker spaces and bringing project-based learning pedagogies and hands-on laboratory experiences to their undergraduate engineering programs. There is a tension rooted in ABET accreditation standards (current and proposed) for what is expected to be taught in computing and engineering undergraduate programs, how to assess and what values about our enterprise of engineering education.

To better understand how Making can be used a learning tool for pre-engineering students, university students, and adults, we must first understand what skills, specifically, Makers are learning. We interviewed 74 Makers to discuss artifacts they had created for presentation at Maker Faires and then compared the skills and knowledge they identified learning with current ABET standards for computing programs and select engineering/engineering technology programs. By finding the specific areas of intersection between the skills used in making and the skills associated with ABET student learning outcomes a-k, and program criteria, we can better understand what skills young makers may be entering college with as well as what engineering skills more broadly can be successfully taught through self-guided, project-based learning. Under a theoretical framework of constructivist grounded theory this study used the qualitative research methods of artifact elicitation interviews to collect the stories of Young and Adult Makers about the skills they used to create artifacts displayed at Maker Faires. A total of 34 self-identified Young Makers, age 7-17, and 40 Adult Makers, age 18-60+, were sampled purposefully and stratified by experience (through their formal education, informal engineering education, and tinkering activities) and membership in an underrepresented group based on ethnicity and gender. Their interviews were then coded with ABET student learning outcomes a-k plus, proposed ABET student learning outcomes, and additional program-specific criteria. With recent proposed changes to ABET student learning outcomes, this work can inform and highlight practices for learning outcomes that are otherwise undervalued (those that will be contracted or combined), as well as present alternative approaches to disciplinary knowledge construction and technical competence.

Implications

Preliminary findings indicate the critical and significant involvement of parents in the additive innovation networks of Young Makers are a part. Parents of Young Makers enable participation in making by supporting their children financially, technically, logistically, and emotionally. They also have strong opinions about the benefit of Making for their kids, so we plan to expand our interview strategy to include parents.

This study will advance the currently limited knowledge of the Young Maker community by developing theory characterizing Young Makers and their pathways through the lens of formal engineering education. The aim is to establish evidence as to how Making benefits Young Makers and affects their pathways to STEM majors and related careers. By highlighting such connections, the results will inform subsequent planned future research on the accreditation of informal and formal Maker activities.

This study could inform future innovation in formal K-12 STEM pedagogy based on successful attributes of informal engineering education and tinkering activities.

The results of this study will transform the conversation of who Young Makers could become, linking Making with engineering in the same way that students who excel in science and math are pointed toward engineering by parents and career counselors. By sharing a diverse (by age, gender, ethnicity) set of success profiles of Young Makers widely in the formal education system (to students, K-12 school administrators, university leaders, and admissions officers) and to Young Makers both online and at Young Maker community events, we aim to illuminate pathways for Young Makers to become the engineers of the future.

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