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

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Dr. Lande is the PI on the NSF-funded project Should Makers Be the Engineers of the Future? He is a co-PI on the NSF-funded projects: Might Young Makers Be the Engineers of the Future?, I-Corps for Learning: Leveraging Maker Pathways to Scale Steam + Making Outreach Programs, Instigating a Revolution of Additive Innovation: An Educational Ecosystem of Making and Risk Taking, and Increasing Learning and Efficacy about Emerging Technologies through Transmedia Engagement by the Public in Science-in-Society Activities. He was also a participant in the NSF Innovation Corps for Learning 2015 cohort (Leveraging Maker Pathways to Scale Steam + Making Outreach Programs) and served as senior personnel / instructional team on the 2014 pilot for NSF’s Innovation Corps for Learning (I-Corps-L).

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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.
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Introduction

Engineering is the field of applied problem solving. This makes it different from other fields of study requiring from its participants more than knowledge of facts but also work towards a solution. Problem decomposition and generating alternatives and implementation are all part of it as well. Success as an engineering student or a professional engineer requires some understanding of designing in context and an interest in solving problems. The skills and dispositions of engineers are as important to their success as the knowledge that comes with years of study of math and science, and the frustrations along the way. Stevens describes the engineering educational experience as one of a “meritocracy of difficulty,”¹ the general perception that the journey needs to be difficult to be worthwhile. A reflection of this on the K-12 student, and primary and secondary education at large, makes one consider where and how the requisite “grit”² is forged.

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”³⁴vision, 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 events⁵, we start to see evidence of roles in the learning ecology⁶. 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 pathway⁷ to interest and majoring in engineering, and engineering careers.

Young Makers

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 students⁸⁹ but is not rooted in similar standards and expectations at the K-12 level. The Next Generation Science Standards (NGSS) itself, in a report summary, caution that it is a set of standards, not a curriculum¹⁰. They “reflect what a student should know and be able to do—they do not dictate the manner or methods by which the standards are taught.” A Maker Mindset is rooted in practice, not in core ideas. So while Makers could work within NGSS, the curriculums built with NGSS in mind might not provide enough practice to fully introduce and instill the knowledge, skills, and attitudes that students are expected to know.
Methods

Maker Faires\textsuperscript{11} have been around as an outlet for creative and innovative people since 2006. Since then, flagship faires have grown to massive events that host over 100,000 people. At these large, public events, our research team identified Young Makers that would be interested in talking about their projects on display and conducts interviews with them. Over the course of three years, we have generated a lot of data in the form of the interviews with both the child and a parent, as well as follow ups that allow more thorough discussion.\textsuperscript{5} Forty (40) self-identified Young Makers, age 7-17, and 25 parents of young makers were interviewed about the artifacts they created and displayed at the Bay Area Maker Faire and the World Maker Faire in New York. Follow-up critical incident interviews were collected for 13 young makers, and 6 parents.

In order to understand the nature of a Young Maker’s learning ecology, the Young Maker interviews were inductively coded, looking for instances where participants directly spoke about how they make and who influences them. There is definitely a strong sense of community both at the fairs as well as within the data set. Past deductive analyses of the data set have shown us the many benefits of Making, in how it is manifested in the child. These Maker attributes and dispositions are valuable, and largely exhibited by engineers everywhere. Inductive analysis of this data points to the importance of family and others in the Making process. Hence, this paper focuses on analyzing the learning ecology of the child and how the roles of people in these children’s lives can help to develop them from a bright, engaging, young prodigy to the engineer of the future. Our research questions, specifically, are

\textbf{(RQ1) How do the roles in the learning ecosystem of a Young Maker create and define maker family values? and}

\textbf{(RQ2) How do these values translate to characteristics of successful engineers?}

Results

\textit{Maker Family Values}

The active dispositions and overall attitude are created and defined by the values of the Maker Family, which is not necessarily (just) the Young Maker’s biological family, but rather those who make up the learning ecology of the maker space. Almost every maker works with others in their learning ecology in some capacity, showing the profound influence that a learning ecology can have on the making process.

Children have what Maria Montessori calls an absorbent mind. When defining this, she writes, “Impressions pour into us and we store them in our minds; but we remain ourselves apart from them, just as a vase keeps separate from the water it contains. Instead, the child undergoes a transformation. Impressions do not merely enter his mind; they form it. They incarnate themselves in him.”\textsuperscript{12} Within the family itself are those who guide the child’s development. Maker Families generally have a Montessori type of approach to parenting, valuing independence and aiding in whatever self-directed task the Young Maker has set their mind to. The families are very diverse, but when looking at the roles they play in the learning ecology of
the child, trends emerge due to the common values and how those manifest themselves in the learning ecology. The roles identified below that appear in Maker Families all underscore this set of educational values. The Maker Family Values are the same as those preached by Maria Montessori, which are centered on the child and their development.

Figure 1: Makers' responses when asked, "Who do you make things with?" from

<table>
<thead>
<tr>
<th>Only my family or myself</th>
<th>0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Others (net)</td>
<td>50%</td>
</tr>
<tr>
<td>With co-workers</td>
<td>20%</td>
</tr>
<tr>
<td>With people to whom I am able to give advice/instruction</td>
<td>15%</td>
</tr>
<tr>
<td>With people who are able to give me advice/instruction</td>
<td>10%</td>
</tr>
<tr>
<td>With hackerspace/makerspace members</td>
<td>5%</td>
</tr>
<tr>
<td>With people I connect with online</td>
<td>0%</td>
</tr>
</tbody>
</table>

Total Respondents

Self-Directed Young Makers

The preeminent disposition of makers is their sense of self direction. All making projects are chosen because they address a problem that is immediate and understandable to the Maker. Other characteristics of Makers, such as their sense of community, risk taking, and playful invention are all indicative of the dispositions and inclinations that they have been taught since birth. Making is essentially an outlet for these characteristics, a genuine source of motivation for young learners. These attitudes and motivations align with those of engineering, and has a place in a young engineer’s education.

Makers possess a wide range of technical skills almost always without formal training. The role of teacher is an important one, as these kids seek to learn all they possibly can to solve whatever problem they set their mind to. The example set by the teacher role-player is what guides the developing child into the curious, self-directed learner that Young Makers are.

Many Young Makers get their start by solving problems immediate to themselves. Whether it’s to make their chores easier or to make everyday life more convenient, a lot of these projects take place around the house. Naturally, the other family members are witness to the Making process, and oftentimes contract the Young Maker to tackle a problem of their own. The necessity of the role of client is made evident by the exchange below,

Interviewer: What are the steps you go through when you decide to create a new invention?

Young Maker: I decide I want to make something. I ask Mom what she wishes existed. She says she doesn't know and I keep badgering her until she tells me something that is actually buildable. Then I go and I say, “OK, how do I do this?”
The approach to solving a client's problem versus one of their own is very different. While the technology used would be the same, the process of understanding the problem completely and knowing how to address various criteria of the client is one that will be valuable to the Young Maker. Communication skills will be put to the test in this situation, in a setting where they are completely comfortable. These skills are further developed when the confident Young Makers present their project to other likeminded people at Maker Faires.

*Facilitator Role*

Perhaps the most obvious role in a maker family would be that of the facilitator, the supplier of materials and space needed to make. This role was almost always a figure who acted like a Montessori-type guide. Meaning that instead of assigning tasks and projects, they laid out goals to guide the makers to solve problems of their own. One young maker spoke of their facilitator saying,

> My pre-engineering teacher kick started my middle school making experience. What he was really good at was instead of being those known parents in our competitions that will be the ones to build the robot and not even let their kids touch it, Mr. B was one of the teachers that would basically just sit back and he want you to discover the rules, and discover what you can and can not do yourself.

The idea of leaving the child to explore the bounds of a problem themselves allows them to get a better understanding of real life engineering lessons. It also instills in the child a knowledge of how to approach new topics, creating lifelong learners.

*Teacher Role*

An additional role is that of a teacher, which is frequently seen when a parent comes from a technical background and is able to get involved with the more difficult aspects of making a design work. However technical experience is not even a must, because anyone can be an example of creative thinking and other dispositions. One young maker described his father as his chief influence saying,

> [A big influence on my making is] my dad. He's an artist. He's definitely not a scientist, so I wouldn't call him an engineer per se, because he doesn't have a lot of the mathematical reasoning that I put behind my engineering. But he's definitely a maker in the way that he innovates and just takes anything that he has and makes do with it, makes it work somehow, fixes it, sort of like MacGyver, but Indian version.

*Peer and Near Peer Support Role*

Siblings or others that the child views as peers also have roles in the learning ecology of a maker family. Whether it’s as someone to bounce ideas off of, or a rival, making is definitely a process that many like to involve their peers in. One Young Maker describes her process:
Interviewer: Who all do you do your making with? You said family and friends?

Young Maker: Yeah. My brother and I are a tag team when it comes to this kind of stuff. I'll usually think of the idea. I'm usually the visual person. Then my brother will say, "We need to CAD it like this." Then my dad will say, "Or we can be more efficient and do it this way," because he's better at it than we are. Other than that, we'll go to our architect's club and say, "What do you guys want to build? We know how to 3D print. We know how to program with Arduino. We can help you with this."

Working with others familiarizes children with the dynamics of teamwork, and also supports the development and growth of communication skills. Hearing other perspectives on a problem and needing to explain their own ideas, is a type of community building that will serve them throughout life.

*Designer and Peer Role*

Another identifiable role in the Making process is that of a designer. If a more realistic, or more technical solution is required to solve a problem, many Young Makers will reach out to those in their learning ecology for assistance. The Maker below describes the relationship with their father as an amalgamation of designer with the Montessori-type teacher.

> I mean there are a lot of things that their insight has been invaluable, especially because ... Well, for example, whenever I used to do a science fair project as a child, my father would be there supervising and giving me tips on some of the projects that I ever messed up, because even though he was an artist, he was still this curious child at heart, so he would always be like, "Oh, I wonder should we put in that liquid, like see what happens." He would always be with me in the kitchen doing that.

What is noteworthy about the designer, as well as the other roles in the learning ecology, is that they are helpful without being assertive or overbearing. By working alongside Young Makers, and asking them design questions, the designer can guide a child's project without taking it out of their hands. Allowing the child to express themselves as uniquely as they want is the whole point of making. One kid described his makerspace saying, “it's the bubble from the rest of the school. That's where we can be ourselves, we can build, we can have fun.”

*Discussion: Family Support Ecosystem*

The family, or whomever surrounds a child as they develop, undoubtedly has the most profound effect on what it is the child learns, and what dispositions they will use throughout their life. Maria Montessori writes, “We used to say it was the mother who formed the child; for it is she who teaches him to walk, talk, and so on. But none of this is really done by the mother. It is an achievement of the child. Should the mother die, the baby still grows up and completes his work of making the man... he takes in the habits and customs of the people among whom he happens to be living” 11. The Maker Family values Maker attributes, which is made evident in the function of their roles in relation to the Young Maker.
By pressuring the child's learning ecosystem, it is possible to guide the child's inner teacher towards standards such as NGSS and ABET in the way that making already is. All the active roles in the Young Maker's ecosystem act on the Maker Family Values to surround the child in a Montessori-type atmosphere. In this setting, the child develops the attitudes and dispositions of a maker. They are the ones who do the making and are only provided with help and information that they themselves seek out.

Seeking out help, whether online or with a person in their learning ecosystem, is crucial to the making process. This sort of additive innovation is what drives a Maker’s project forward when they are struggling to overcome a specific task or challenge. Being an active member of this community requires that one is comfortable communicating their ideas, and confidence in themselves, knowing that they have good ideas to contribute. One Young Maker describes how this concept affects his making in the exchange below,

Interviewer: What do you like the most about this?

Young Maker: That I can do anything. What I like is, I tend to like a lot of open-source projects because I can find what someone's done and say, ‘Oh this is cool but it would be great if it did this.’ Then I can add stuff to it. That's why I tend to leave some of my projects open-source, because someone smarter than me is going to come along and say, ‘You know what? This code is bad, there is a better way to do this’ or, ‘You know what? I want 3 lights, not 2 and I only need 1 outlet.’ They are going to want to modify it. If I patent it or leave it closed-source, no one can come along and do that.

This type of community with its genuine interest in the projects along with its openness to almost any project conceivable teaches teamwork and the sharing that is a part of that. The playful inventing nature of the movement allows Makers to take risks with their projects, as the consequences of something not working are trivial compared to that of a classroom or even science fair.

Figure 2: Makers' responses when asked, "What collaborative activities do you engage in?" from 5

![Figure 2: Makers' responses when asked, "What collaborative activities do you engage in?" from 5](image)
The free thinking made possible by this learning ecology is worth fostering, as it builds up the Maker Mindset to produce bright, young people who are familiar with many necessary fundamentals for engineering success.

The self-direction that comes from this creative freedom has virtues of its own. The level of personal investment that comes with this self-directed learning surpasses that of any classroom setting. One Maker talks about his self-education process saying,

If I can't find it in a book, and I will check not only user guides but also project books. I'll say, “Oh well, this project involves photons that have to communicate over serial, I can use that.” If I still can't find it, Google is my friend. If that doesn't work, I start asking people and eventually I will find that information somewhere from somebody.

This fervent pursuit of knowledge is made possible by this Montessori learning ecology. The drive to conduct such research is not hard for these Young Makers to find as they are excited to be doing something that genuinely interests them. Allowing the child to educate themselves will create the lifelong learners that engineers have to be in the rapidly advancing technological landscape that exists today.

The Makerspace and materials provided by the facilitator, set the bounds for the Young Makers problem solving ability. Practical ingenuity is a preeminent attribute of Makers, and it is fostered through the Montessori-style approach to guiding the child's action. She writes, “We then found that individual activity is the one factor that stimulates and produces development”\(^1\). A Young Maker describes their process in the exchange below,

**Interviewer:** Cool. Now we'll bounce into a little more discussion on your experiences personally. How do you think you became a Maker?

**Young Maker:** My Dad always likes fiddling around with electronics stuff and I mostly just ... When I was smaller I tried ... I liked to build little sculpture things out of the extra electronics parts. Not actually real circuits or anything, but I would build little art projects with bits of wire and batteries and stuff. Then, later I started hooking up batteries to various things and seeing what they would do. Then I started formally deciding to make a project.

Having raw materials and the temptation to play, whether with LEGO, battery packs or Erector sets, is all it takes for some to develop a disposition towards building and tinkering with technology. The limitations of the home challenges Makers in the design process, giving them a more complete understanding of what it is they have to accomplish.

**Translating Support for K-12 Young Maker Student to Future Pathways**

Learning in the unique Maker community promotes a number of ABET [8, 9] expectations for engineering graduates. Within ABET student learning outcomes “a-k”, one engineering guideline that stands out as being a feature of a Maker Mindset is “(g) an ability to communicate effectively.” By explaining their projects and ideas to anyone who will listen, Young Makers are articulate and perceptive. Additionally, the peers in the learning ecology of the Young Makers teach them, “(d) an ability to function on multidisciplinary teams.” The personal investment that
is tied with the self-directed nature of these projects, create youth who are familiar with learning things for themselves. An additional ABET standard for engineers is, “(i) a recognition of the need for, and an ability to engage in life-long learning,” a disposition that is a fundamental part of the Maker Mindset. Even when a Makerspace has limited tools and resources, it still benefits those who have the Maker Mindset. The practical ingenuity that is a part of Making in the real world, confronts makers with design constraints that they must think around. The “(c) ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability,” that ABET calls for in engineers is just an extension of the practical ingenuity that Makers apply to their personal projects. These characteristics are all in harmony with engineering standards, and are necessary to create successful engineers.

Verbal communication and teamwork is something that many Young Makers are familiar with, and is something that many engineering student struggle. The mindset that is an intrinsic part of making is what is most valuable about this movement. Dale Dougherty, a prominent figure in the Maker Movement writes, “We can create a workshop or makerspace, and we can acquire tools and materials, but we will not have succeeded at creating innovative thinkers and doers unless we are able to foster a maker mindset” 13. Self-identifying Makers are self-directed, lifelong learners who have a genuine passion to do what they set their mind to. The dispositions and attitude that Makers gain are what will make them successful throughout life.

A Tesla Motors job ad reads, “You will be expected to challenge and to be challenged, to create, and to innovate. These jobs are not for everyone, you must have a genuine passion for producing the best vehicles in the world. Without passion, you will find what we're trying to do too difficult.” With passion being the most important factor in the quality of work done, one must ask where it comes from, and how it can be fostered. However, passion is a Maker’s only motive, and thematic analysis of them shows how this passion is instilled, allowing that method to be emulated. An example of a space that fostered similar values and produced successful engineers is the Homebrew Computer Club. Lee Felsenstein, designer of the Osborne computer, and Steve Wozniak, whose success as an engineer is undeniable. When writing on his design process, and how the Apple II came to be, Wozniak says, “I found ways to optimize and combine different parts of the circuits and make things with fewer chips. It's great to show off at a club that you use fewer chips than someone else. I did it for no other reason.” The Homebrew Computer Club valued attributes similar to those of the Maker Community, one that is fueled by additive innovation and practical ingenuity. Limitation by the cost of parts, and freely trading them and ideas with their peers, is what fueled the development of solutions to their engineering problems.

Just imagine how powerful Making can be as an avenue to bring forward and amplify student interest in STEM (science, technology, engineering, and math) or STEAM (science, technology, engineering, arts, and math) to inspire and engage a generation of K-12 students. Already Mini-Maker Faires are being organized for elementary, middle and high schools around the world 15. It could activate students to build and make, and realize a pathway forward to become engineers. If the classroom accepted the Maker movement as a way to reach the standards that it set for itself, the next generation of engineers will be innovative and intuitive enough to be productive in a constantly evolving field.
References


