New Orleans Jazzed about Engineering Education

Paper ID #15605

How Can Maker Skills Fit in with Accreditation Demands for Undergraduate Engineering Programs?

Mr. Aubrey Wigner, Arizona State University

Aubrey Wigner is a PhD candidate in Human and Social Dimensions of Science and Technology at Arizona State University. He has an undergraduate degree in Chemical and Biochemical Engineering and a Masters in International Political Economy of Resources, both from the Colorado School of Mines. His research focuses on integrating Makerspaces and Hackerspaces with higher education to enhance learning through hands on interdisciplinary practices. He is also interested in how organizations and individuals engage in technological innovation.

Dr. Micah Lande, Arizona State University, Polytechnic campus

Micah Lande, Ph.D. is an Assistant Professor in the Engineering and Manufacturing Engineering programs at the Polytechnic School in the Ira A. Fulton Schools of Engineering at Arizona State University. He teaches human-centered engineering design thinking, making and design innovation project courses. Dr. Lande researches how technical and non-technical people learn and apply design thinking and making processes to their work. He is interested in the intersection of designerly epistemic identities and vocational pathways. Dr. Lande received his B.S in Engineering (Product Design), M.A. in Education (Learning, Design and Technology) and Ph.D. in Mechanical Engineering (Design Education) from Stanford University.

Dr. Lande is the PI on the NSF-funded projectShould 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,andIncreasing 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 2014pilot for NSF's Innovation Corps for Learning (I-Corps-L).

Dr. Shawn S. Jordan, Arizona State University, Polytechnic campus

SHAWN JORDAN, Ph.D. is an Assistant Professor of engineering in the Ira A. Fulton Schools of Engineering at Arizona State University. He teaches context-centered electrical engineering and embedded systems design courses, and studies the use of context in both K-12 and undergraduate engineering design education. He received his Ph.D. in Engineering Education (2010) and M.S./B.S. in Electrical and Computer Engineering from Purdue University. Dr. Jordan is PI on several NSF-funded projects related to design, including an NSF Early CAREER Award entitled "CAREER: Engineering Design Across Navajo Culture, Community, and Society" and "Might Young Makers be the Engineers of the Future?" He has also been part of the teaching team for NSF's Innovation Corps for Learning, and was named one of ASEE PRISM's "20 Faculty Under 40" in 2014.

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.

How Can Maker Skills Fit in with Accreditation Demands for Undergraduate Engineering Programs?

Abstract

In this paper, the skills Makers are learning are categorized according to their fit with existing and proposed ABET standards. Makers, both young and adult alike, learn a variety of skills to create technically sophisticated artifacts of personal interest. Here we argue that making (open ended, student led project based learning) and the Maker Mindset can provide a useful template for teaching some ABET applicable skills and attitudes. This paper demonstrates that ¾ of makers are learning how to communicate technical details to a wider audience, ½ are learning valuable techniques to foster lifelong learning, ½ are learning how to apply engineering knowledge to solve problems, ½ are learning specific skills applicable to electrical engineering and manufacturing engineering programs, ⅓ are working on multidisciplinary teams, and ⅓ are designing systems with realistic constraints. Each of the above categories is part of ABET's accreditation process for engineering programs. Making offers a potential lens to highlight those areas which may be lagging in a more traditional engineering education. As part of ABET accreditation criteria, 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 it, and what is valued about the enterprise of engineering education. 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.

Introduction

There is an influx of interest in Making and an ever-growing community of Makers interested in engineering at the undergraduate level. 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 76 Makers to discuss artifacts they had created for presentation at flagship Maker Faires. 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. Skills Makers identified as learning are categorized according to their fit with existing, and proposed, ABET standards for selected engineering, engineering technology, and computing 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.

In this research paper, 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. Here we argue that making (open ended, student led project based learning) and the Maker Mindset (failure-positive, collaborative, playful) can provide a useful template for teaching some ABET applicable skills and attitudes. This paper demonstrates that ¾ of interviewed makers are learning how to communicate technical details to a wider audience, ½ are learning valuable techniques to foster lifelong learning, ½ are learning how to apply engineering knowledge to solve problems, ½ are learning specific skills applicable to electrical engineering and manufacturing engineering programs, ⅓ are working on multidisciplinary teams, and ⅓ are designing systems with realistic constraints. Each of the above categories is part of ABET's accreditation process for engineering programs. Communications skills, the ability to engage in self-directed learning, and the ability to function in a real world work environment (teams and constraints) are recognized to be areas that traditional engineering training is lagging in.[1] Making offers a potential lens to highlight those areas which may be lagging in a more traditional engineering education. Furthermore, as part of ABET accreditation criteria, 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.

Under thematic analysis this study used ABET criteria as a framework for coding artifact elicitation interviews used to collect the stories of Young and Adult Makers about the skills they used to create artifacts displayed at Maker Faires. A total of 36 self-identified Young Makers, age 12-17, 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.

What is a Maker?

The Maker Movement is an emerging and developing sub-culture that values the tinkering, hacking, re-making, and creating of technical artifacts. Makers are rich in creative confidence, with expertise in the ability to learn new skills as needed rather than already possessing immediate solutions to the problems that they encounter.[2] Creative confidence, in terms of Design Thinking, can be summed up as a failure positive mode of learning where the creator trusts in their own ability to solve problems.[3] This confidence comes from an understanding that problems have many solutions, and through practical experience, one can learn those solutions. Making comes from an imaginative, creative mind-space, and is often done outside the confines of established engineering education curricular activities.[4] Making has a do-it-yourself ethos and is historically rooted in efforts like *Popular Mechanics* magazine who demystified everyday stuff for hobbyists and the *Whole Earth Catalog: Access to Tools* [5] who surveyed everyday tools for the counterculture movement of the 1960s. Additional real-world touchstones are the growth of Radio Shack stores and the 1980s television program *MacGyver* where the lead character would resolve each episode's predicament by fashioning an escape plan out of found objects.[6] Technology and sharing of information via the Internet has greatly increased the ability for smaller communities with shared interests to coalesce and grow.

The label "Maker" is a self-determined one assigned by affinity to or involvement in a larger Maker community. Both our interviewees as well as the founder of MAKE Magazine, Dale Dougherty, would suggest that all people can be makers, with self-identification as a Maker and the desire to tinker being the only real criteria.[7] Makers are do-it-yourself-minded individuals participating in informal communities (doing-it-with-others) that support and celebrate building and prototyping technical proof-of-concept exploration and ad-hoc product development. A Maker is a modern-day tinkerer and hands-on doer and fashioner of stuff. The range of expertise could be large but novices and experts alike share an enthusiasm and appreciation for building and creation. Individuals and groups embark on projects of all sorts, led primarily by their interests and curiosities, informed by their skills or the skills they want to learn. For example, one might make creative efforts like fire-breathing robots as performance art, combining contributions from community members with electrical, mechanical and embedded systems know-how. Makers exemplify the collaborative model of *additive innovation* by seeking and offering inspiration in their community, sharing and learning recipes with others, iterating on their own designs, and sharing artifacts of their designs back with the community to inspire others.[8]

Makers participate in communities of practice,[9] gathering with like-minded individuals and groups to learn skills and share interests and affinities. They populate maker spaces and hacker spaces[10] and use commercial ventures like Tech Shop[11] to gather with other Makers. A significant part of such participation is to benefit from opportunities to continue learn from, teach and mentor other Makers.

The Maker Mindset

In the context of this paper, the Maker Mindset is considered the attitude that makers use in their problem solving process. The primary components of this mindset are a creative confidence (a failure-positive approach to problem solving), collaborative sharing of knowledge between makers and a sense of playfulness that drives project decisions and guides the learning process.[12] Additionally, making is approached with a growth-mindset where individuals strongly hold the belief that knowledge and skills can be acquired by anyone with the motivation to learn.[13] These approaches to problem solving can be best summarized in the words of our interviewees.

> *Any problem you're approaching, it doesn't matter if you're problem is to design a dowel connector or that one person on your team who you really can't work with, you are going to apply the same skills in making. Try something, maybe it won't work, you can try again. The world does not end if you're initial design rolls off*

the table when you connect it to a dowel. The world does not end if your initial design has holes that are the wrong size. The world does not end if you're initial design is not big enough. You can move on and try again, everything is an iteration and throughout your whole life you're going to be varyingly running through iterations or tripping and flailing your way through your iterations, but you can always try something again and failure is part of your process, not the end, you're not done when something fails.
– Emma 7th grade Maker

The message I'm trying to get across is that the Arduino controller is an incredible versatile thing and it's great for fun and it's great for work. So I'm a scientist by day and I make costumes by night and it's really useful for both of them.
– Mia, Bioengineering Postdoc

The engagement with materials, design, building and making, has been long used by artists and designers to grow creativity as well as practical skill in creating. The Rhode Island School of Design, for example, engages its students in critical making to enhance their abilities as designers through hands on interaction and the creation of physical artifacts.[14] Likewise, for engineering educators, this mindset offers the potential to open up some engineering classes to be project based, student led, and evaluated on process and teamwork over final outcomes. While not all classes could benefit from these traits, valuable skills for communications, project design and analysis, and lifelong learning, as well as practical skill at building and interacting with the artifacts of engineering can be gained from classes structured in such a manner.

Research Design

Under thematic analysis as a theoretical framework, this study used the tool 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 36 self-identified Young Makers, age 12-17, and 40 Adult Makers, age 18-60+, were interviewed. The interviewees include both adult makers as well as pre-college makers. Allowing for a clear view of adults post-college as well as those entering college in upcoming years. Participants engaged in ~15 minute interviews about the artifacts they created and displayed at two flagship maker faires, the Bay Area Maker Faire and the World Maker Faire. Their interviews were then coded with ABET student learning outcomes a-k, proposed ABET student learning outcomes, and additional program-specific criteria. Coding was based on participant views of what they had learned to create their object as well as the interviewer's observation of their artifacts.

Population and Sampling

The two flagship Maker Faires in New York and the Bay Area average approximately 1000 makers presenting their creations each year, as well as 100,000+ attendees.[15] We estimate the population to contain around 200 young makers and 800 adult makers, with a fair amount of overlap between presenters per year and per event. For purposes of confidence intervals, we used an N=1000 to represent the overall population of presenters at any given Maker Faire. We chose interviewees 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. This stratification allows for a greater representation of the broad Maker community, both at Maker Faire and nationally, that could have remained invisible if interviews were taken at random.

Data Collection

Data was collected using a screening questionnaire followed by an immediate 15 minute interview with the presenting maker and their artifact(s). Our team used iterative sampling at Maker Faires to identify makers by education level, age, gender, and ethnicity to provide a broad overview of the maker community.

Screening Questionnaire

The questionnaire consisted of short answer questions designed to guide our future sampling groups and collect basic demographic data (see Table 1). The results were collected in a spreadsheet that was used to guide our stratified purposeful sampling strategy and was also used to contextualize the artifact elicitation interview questions.

Table 1: Screening Questionnaire

Are you a Maker?	Primary Strata
How many years are you a Maker?	Secondary Strata
As a Maker, what do you Make?	Theoretical Sampling
Why are you attracted to Making?	Theoretical Sampling
Have you been involved with any group Maker activities?	Primary Strata
Have you taken any engineering classes or have an engineering degree?	Primary Strata
Do you have an engineering related job/career?	Secondary Strata
Ethnicity, Gender	Primary Strata
Age	Secondary Strata

Artifact Elicitation Interviews

Semi-structured artifact elicitation interviews,[16] based on the research method of photo elicitation,[17,18] were used to elicit "thick description" from participants.[19] Interviews were conducted in person with 76 Maker participant to examine the pathways related to engineering that had been followed toward the creation of the artifact on display. For the interviews, each participant was located at their exhibit booth at the Maker Faire where they were typically interacting with Maker Faire attendees and showing/demonstrating their creation. Following obtaining research consent, approximately fifteen minutes was spent with each Maker participant, asking them to describe their artifact, show how their artifact works, describe their process for Making, and describe the knowledge, skills, and attitudes they learned or gained from

Making (see Table 2). We asked probing questions about the artifact to elicit "thick description".[19] Questions evolved after each round of data collection based on emergent themes that were discovered during early analysis.

Table 2: Examples from Artifact Elicitation Interview

Can you tell me about what you brought to the Maker Faire? ▪ What technology does it use? ▪ Can you show me how it works?	Knowledge and skills
What knowledge and skills did you have to learn to make this [insert name of artifact]?	Knowledge, skills
Where did you learn these things?	Lifelong learning
How did you come up with the idea for this [insert name of artifact]? ▪ What could you improve in your [insert name of artifact]?	Attitudes

The 76 artifact elicitation interviews were coded in NVivo mixed methods analysis software for the following categories.[20]

Table 3: ABET Criteria 3 - Student Outcomes

a)	an ability to apply knowledge of mathematics, science, and engineering
b)	an ability to design and conduct experiments, as well as to analyze and interpret data
c)	an 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
d)	an ability to function on multidisciplinary teams
e)	an ability to identify, formulate, and solve engineering problems
f)	an understanding of professional and ethical responsibility
g)	an ability to communicate effectively
h)	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i)	a recognition of the need for, and an ability to engage in life-long learning
j)	a knowledge of contemporary issues
k)	an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Table 4: ABET Program Specific Criteria

1)	Broadly applicable to engineering programs
	a) science fundamentals
	b) high level math (calculus, differential equations, etc)
	c) computer aided design (CAD)

2)	Biomedical engineering programs – solve biomedical problems, interaction between living and non-living systems, realize biomedical devices, measure and interpret data from living systems.
3)	Electrical, computer, communications, and telecommunications engineering programs – analyze and design complex electrical and electronic devices, software, and systems containing hardware and software components.
4)	Manufacturing engineering programs – understand materials and manufacturing processes, process assembly and product engineering.
5)	Mechanical Engineering – model, analyze, design, and realize physical systems, components or processes.
6)	Computer Science - Programming without electronic or hardware components.

Program specific criteria are drawn from ABET Accreditation Workbooks, which themselves leave quite a bit up to the subjective understanding of the individual reviewer. Nearly all engineering programs require knowledge of science fundamentals and higher level math. CAD skills, while note required explicitly by most programs, are useful in most forms of engineering and are an example that shows the use of modern engineering tools. Computer science is listed as a separate category to distinguish the very few maker projects which were solely app based rather than those which required both hardware and software components. Finally, Manufacturing Engineering was taken to include prototype fabrication as well as designs that were meant to be broadly distributed and used by a wide audience.

Table 5: Engineering Experience

1)	Has an engineering degree or worked professionally as an engineer (adult)
2)	Wants to pursue education in engineering (young)

For engineering experience we drew from both the artifact elicitation interviews as well as the initial background survey.

Mapping Data to Proposed ABET Student Outcome Changes

After initially coding the interviews based on existing a-k standards, interviews were then mapped to proposed changes in ABET Student Outcomes. Each interview was counted only once per category, regardless of the number of a-k categories present. For example, if a given interview was coded with both (a) and (e), it would be counted as one example of category (1) and one example for category (3). It is worth noting that the proposed changes to Student Outcomes are easier to map to than the previous a-k standard. While in a-k there is some ambiguity as to whether a given individual, for example, applied knowledge of engineering (a) to build something or identified and solved a problem using engineering (e), in the proposed standard it is much easier to simply identify that as applying to (1), or to (3) if they explicitly collected and interpreted data.

Table 6: ABET proposed student outcomes

Proposed Student Outcome	Equivalent to Existing Student Outcome(s)
1. An ability to identify, formulate, and solve engineering problems by applying principles of engineering, science, and mathematics.	a. apply knowledge of mathematics, science, and engineering e. identify, formulate, and solve engineering problems
2. An ability to apply both analysis and synthesis in the engineering design process, resulting in designs that meet desired needs.	b. design and conduct experiments/analyze and interpret data c. design a system with realistic constraints k. use modern engineering techniques
3. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.	b. design and conduct experiments/analyze and interpret data e. identify, formulate, and solve engineering problems
4. An ability to communicate effectively with a range of audiences.	g. an ability to communicate effectively
5. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.	h. broad education to understand engineering in context f. professional and ethical responsibility
6. An ability to recognize the ongoing need for additional knowledge and locate, evaluate, integrate, and apply this knowledge appropriately.	i. lifelong learning
7. An ability to function effectively on teams that establish goals, plan tasks, meet deadlines, and analyze risk and uncertainty.	d. function on multi-disciplinary teams

Results and Analysis

This paper argues that young and adult makers are learning valuable engineering skills, both those represented by ABET Student Outcomes a-k, as well as program specific skills. The knowledge makers are acquiring is relevant to understanding how the growth of makerspaces in universities can be leveraged to meet existing and future accreditation standards. Below, the results are visualized and each section, Criteria 3, Criteria 3 proposed, and Program Specific skills are discussed along with examples of coded interviews to provide a thicker context for the results.

Table 7: Raw Results

ABET a-k	Total Sources	Adult	Young	Percent	CI
(a) Apply sci, eng, math knowledge	33	19	14	43%	11%
(b) Design and conduct experiments	8	6	2	11%	6%
(c) System design with constraints	29	14	15	38%	11%
(d) Function on multidisciplinary teams	20	13	7	26%	10%
(e) Identify and solve eng problems	22	12	10	29%	10%
(f) Professional and ethical responsibility	12	4	8	16%	8%
(g) Communicate effectively	60	32	28	79%	9%
(h) Broad education	35	22	13	46%	11%
(i) Lifelong learning	42	26	16	55%	11%
(j) Contemporary issues	9	4	5	12%	7%
(k) Use engineering tools	13	8	5	17%	8%
Engineering Experience					
Is an engineer (adult)	14	14	0	35%	14%
Wants to be an engineer (young)	18	0	18	50%	15%
Program Specific Criteria					
Electrical and Computer Engineering	43	19	24	57%	11%
Manufacturing Engineering	37	22	15	49%	11%
Mechanical Engineering	21	11	10	28%	10%
All - Science Fundamentals	20	10	10	26%	10%
All - CAD Skills	18	5	13	24%	9%
Computer Science Only	3	1	2	4%	4%
Biomedical Engineering	3	1	2	4%	4%
All - High Level Math Skills	2	0	2	3%	3%
N = 76, 40 adult, 36 young, population = 1000, 95% confidence level					

The raw numerical results are shown here to give the context in which the following visualizations are sited.

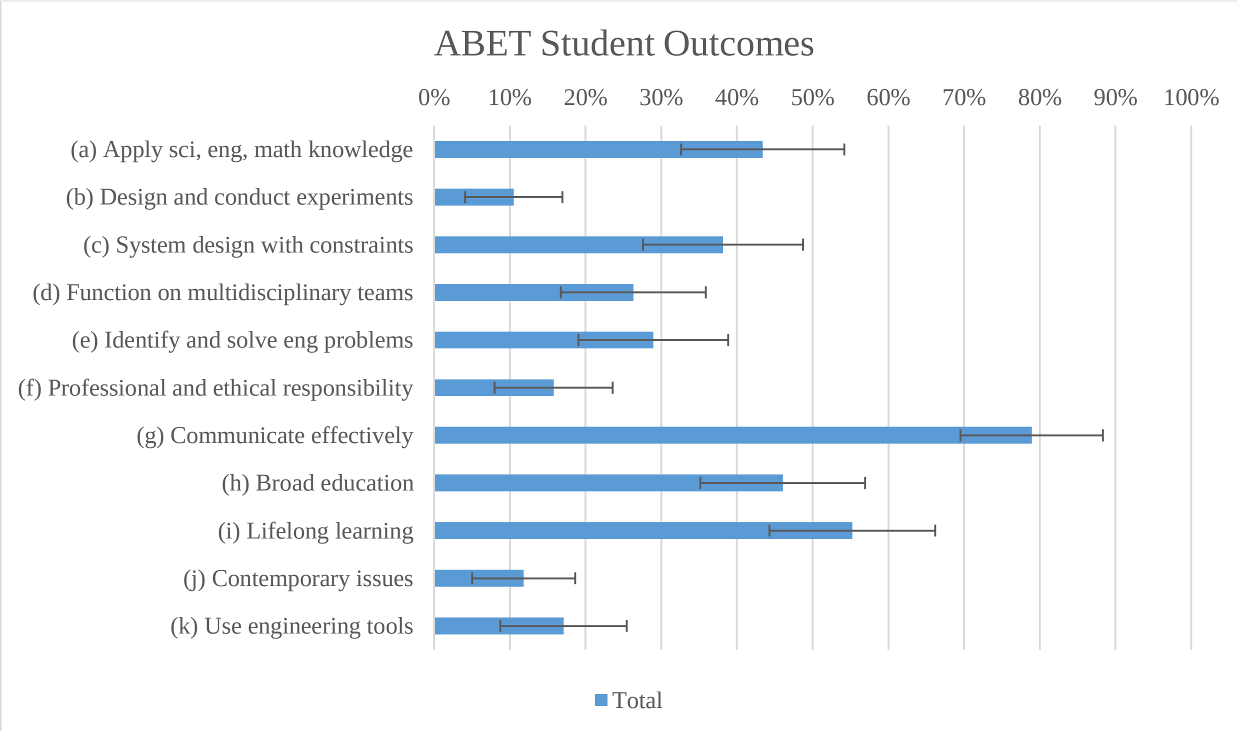

Figure 1: Student Outcomes – Total

In Figure *1*, we can see that the majority of makers exhibited effective communications skills. Almost 80% were able to clearly explain their technical project to a wider audience and/or mentioned specific cases where they effectively communicated in other situations. For example, one young maker designed a PowerPoint presentation and pitched an idea for a makerspace to his local school board. Another young maker produces a YouTube channel describing various science and engineering projects, has published a series of making books, and speaks regularly at maker faires on making and education. An example among adult makers is a group which communicate physics principles to an audience using a gigantic Rube Goldberg machine based on a children's game. Additional areas which makers are acquiring skills are lifelong learning, designing systems or projects within realistic constraints, and the application of science and engineering to solve problems. In the category of lifelong learning, most makers are highly adept at finding out how to solve problems by using internet searches, forming collaborative groups, and digging through existing literature to find solutions to help build their specific projects. The methods used by makers for finding project focused solutions are performed in a just-in-time fashion. When a project requires a solution, the maker finds out how to do it, applies the solution and moves on with the project. This ad-hoc method of contacting fellow makers, reviewing online sources, or forming groups to tackle a problem mirrors problem solving in a real world environment. If makers were imagined as employees in a technology firm rather than hobbyists, this ability to solve problems outside of the baseline knowledge acquired in university would be strongly valued. This willingness and drive to learn and expand their knowledge is an example of the Maker Mindset's focus on growth through experience.

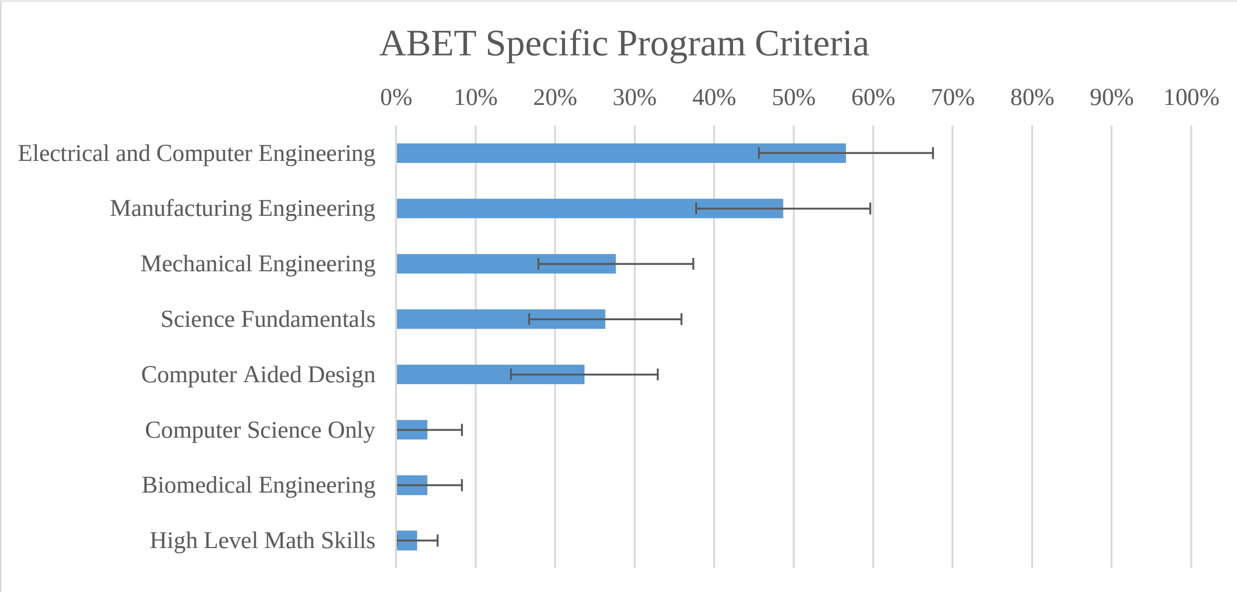

Figure 2: Program specific criteria

In terms of program specific ABET criteria, it is clear that makers are primarily learning the skills associated with building systems with hardware and software components, such as robots, drones, interactive games, and with fabrication techniques. It is worth noting that an area makers are strongly lacking in terms of engineering education is higher math skills. While our data collection methods did not specifically ask interviewees if they used higher level math in the creation of their artifact, only one respondent mentioned using calculus and polar coordinates as a skill learned for their project. This suggests that to effectively use making as an educational tool, explicit mathematical elements may be needed during project creation or evaluation. Methods for doing so are further elaborated on in the conclusion and discussion sections of this paper.

In contrast to higher math, makers are learning a great deal about the integration of hardware and software components to form complex systems. Tony (pseudonym), a 14 year old maker needed to identify and create a prototype solution for his final middle school project. He identified firefighting as a dangerous job which could be performed by robots. He then designed a prototype firefighting robot. This robot used a laptop running Linux to run pathing functions, which were then sent via WiFi to his foot tall robot. The programs to drive the robot were written by him using Python and C. The robot itself was a combination of 3D printed and laser cut components with an Arduino board acting as the local brain for the robot. Mechanically, the robot used four two way wheels so it could navigate corners in a maze without turning. Finally, the robot had a fan attached which it would use to blow out a candle once it had been navigated to the "fire". Tony had analyzed his system and recognized weaknesses in his design; seeing what the robot saw on the laptop had a 30 second delay, stairs would be a problem for the robot, and a fan wouldn't work well on an actual fire. However, as a prototype, he considered it a successful starting point. To take his project to the next level, Tony recognized he would have to learn more about both programming and hardware. Two of our team's assistants, both juniors in electrical engineering, remarked on how this was a more impressive project than many of their classmates would create for a senior project. While Tony's artifact was particularly impressive, even for Maker Faire, and represented examples applicable to almost all of the a-k Student Outcomes and skills applicable to electrical engineering, it demonstrates how allowing a student to choose a problem they're passionate about, and then create a prototype solution can lead to an immense amount of learning.

It is worth noting that more than half of the makers interviewed built systems using software and hardware components, many used fabrication methods associated with mechanical and manufacturing engineering, and around ¼ of makers used CAD programs to design their artifact in 3D prior to creating it. This seems in no small part to be due to the increased accessibility of electronics and fabrication tools. Desktop 3D printers, laser cutters, and cheap, easy to program microcomputers such as Raspberry Pi and Arduino featured prominently in many artifacts.

With regards to pure computer science and biomedical engineering, it is either very uncommon for makers to engage exclusively in these categories or our sample size is insufficient to show a reliable estimate for what makers are learning in these areas.

In most cases, young and adult makers learned skills and behaviors applicable to ABET standards in roughly similar percentages. However, there were a few notable exceptions where the two populations differed in percentage by more than the confidence interval of the combined data. These areas of major deviation are shown below in Figure 3.

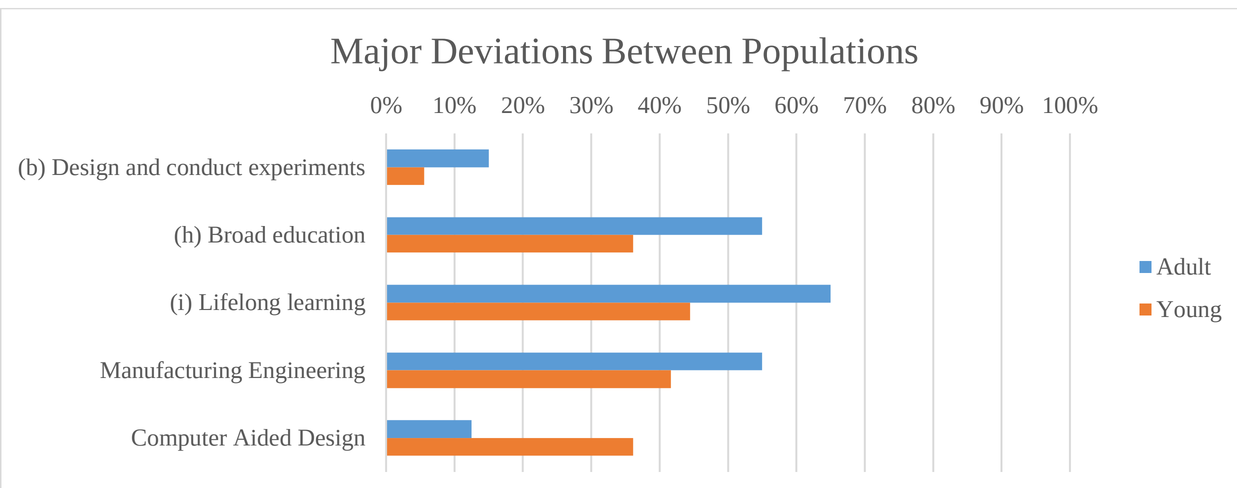

FIGURE 3: MAJOR DEVIATIONS BETWEEN YOUNG AND ADULT MAKERS

Some of these differences, like broad educational experiences and lifelong learning, are unsurprising. Adult makers have, during the course of their lives, been exposed to more levels of education and greater variety in terms of career and experiences than makers 30 years their junior. Two areas of importance however are found in designing and conducting experiments and computer aided design. Older makers were much more likely to see themselves as conducting experiments through their iterative design process than young makers. We hypothesize that this is due to the more formal exposure to the scientific method that adults would have received in college. This finding could also be interpreted as suggesting that Making could be a form of scientific inquiry in the classroom if students were guided in the process. Finally, more than twice as many young makers explicitly mentioned using computer aided design tools in their projects. In many cases, this seemed to be due to being formally introduced to tools such as SketchUp or TinkerCAD in the classroom. The early introduction of CAD software to young Makers could set them up for success when they are introduced to such programs again in a college setting.

The Maker Mindset and Maker skills are equally applicable to the proposed ABET Criteria for Student Outcomes. For the purposes of this study, as discussed above, the proposed revisions for ABET Student Outcomes can be seen as a combination of existing a-k standards. Where makers appear to shine under the revised Student Outcomes are communications skills (4), the application of technology to solve problems in a social context (1, 2, and 5), and their ability to engage in self-directed learning (6). When taken as a whole, Makers are learning to identify and solve problems they care about using technology.

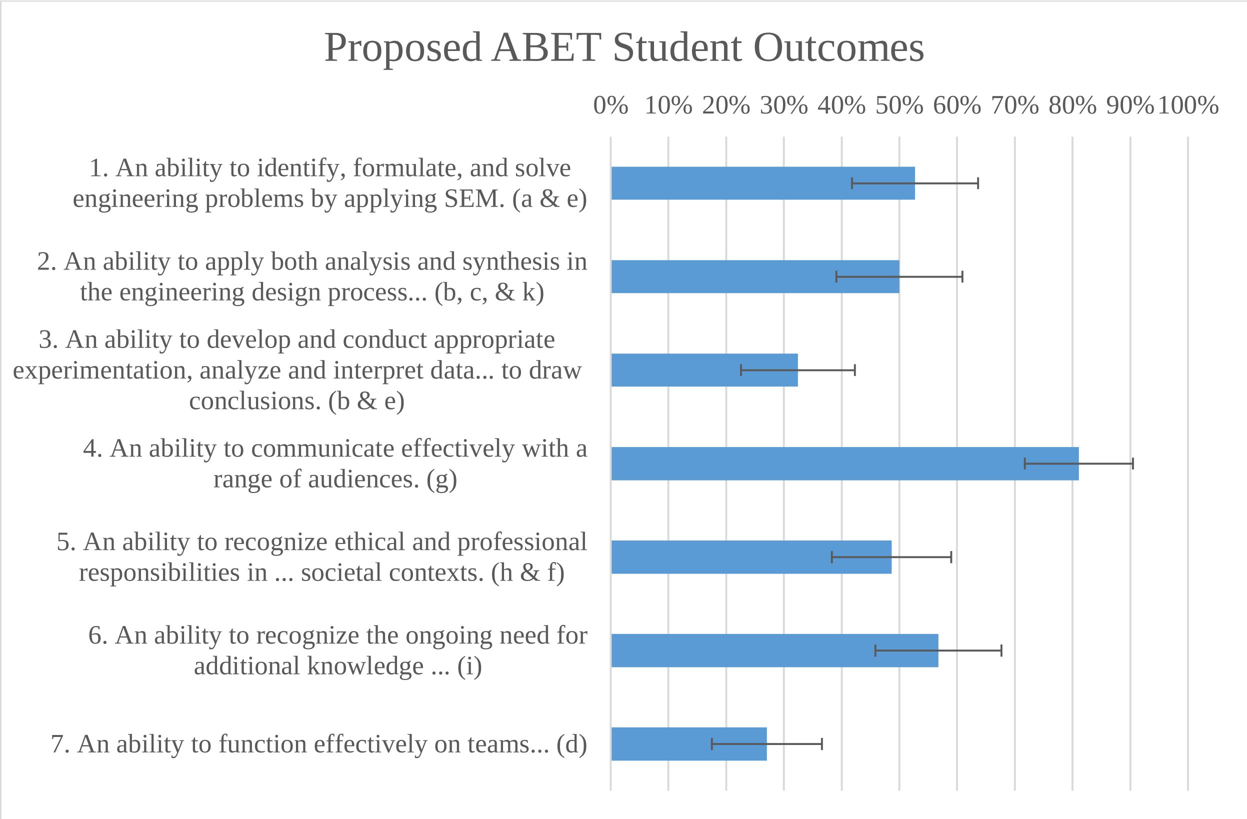

Figure 4: Proposed ABET Student Outcomes

Finally, the maker community is formed of many current engineers as well as future engineers. Nearly half of our adult participants either had been trained as engineers or are currently working in an engineering field. Some of the participants identified making as the hobby that allowed them to renew their love of engineering or inspired them to learn additional engineering skills outside of their original area of training. For example, after retiring from an electrical engineering career, Matt learned 3D design and prototyping to create a Rube Goldberg style amusement park for plastic frogs. Ray on the other hand was trained as a mechanical engineer, but learned about fluids, programming, and web interfaces to create a web-based watering system for his garden. Furthermore, this large percentage of adult engineers in the making community provides a social mentorship network which young makers are able to tap. Fifty percent of young makers identified engineering or computer science specifically as their major of choice going forward into college. These pre-engineering makers will likely enter their programs with an expectation that project based learning will be part of their education.

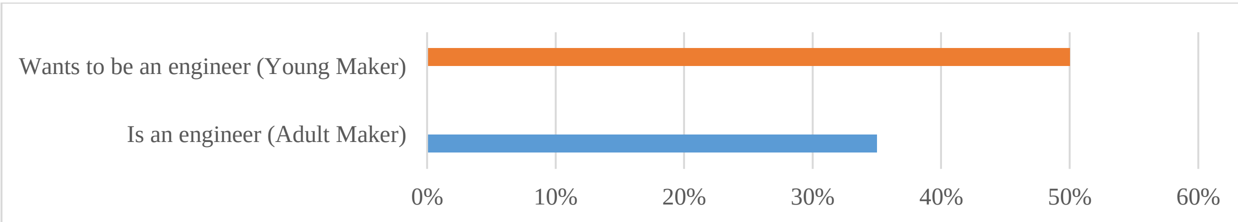

Table 8: Engineering Training and Goals

Discussion and Conclusion

Making, in the context of student led project based learning, is producing young people and adults who possess valid engineering skills which are applicable to ABET accreditation. The Maker Mindset, with its focus on celebrating failure, learning through hands-on iteration, and collaboration between makers could well be adopted in some engineering courses to instill many of the ABET Student Outcomes as well as program specific criteria for electrical, mechanical, and manufacturing engineering. Specifically, the ability of Making as a form of project based learning to instill a high level of communications ability, strong collaboration skills, the ability for self-directed learning, and perseverance is valuable to traditional engineering programs. This value remains, in an accreditation sense, whether or not Student Outcomes are revised as proposed.

Additionally, maker faires and artifact elicitation interview protocols themselves offer a possible way for engineering educators to harness the Maker Mindset for their students. In a student driven, project based course, a mini-maker faire, the equivalent perhaps of an art class's gallery final, combined with professors asking probing questions on the skills learned in the creation, successful or not, of a student's artifact could lead to successfully accomplishing ABET Student Outcomes. While perhaps more time consuming than a multiple choice test, an instructor can clearly determine what skills were used in the creation of an artifact through a semi-structured interview with the student. The authors plan to delve more deeply into artifact elicitation as an evaluative method in further work.

This is not to suggest that Making takes the place of rigorous engineering training. As the data presented in this paper shows, there would be a clear need for the purposeful integration of higher level math into project based making. Making alone does not appear to teach the math skills needed for today's engineer. The integration of higher mathematics into Making could come in the form of post-prototype write-ups. Engineering students could, as often occurs in professional product engineering settings, create and test rough prototypes of their ideas, then, once a working model is established, dig further into the design by creating mathematical models for the object in terms of durability, cost, efficiency, etc. Future research on how to best integrate the qualities of a Maker Mindset with traditional engineering courses remains to be done, but the benefits of doing so are compelling.

References

1. Mills, J. E., Treagust, D. F. & others. Engineering education—Is problem-based or project-based learning the answer? *Australas. J. Eng. Educ.* **3,** 2–16 (2003).
2. Dougherty, D. The maker mindset. *Des. Make Play Grow. Gener. STEM Innov.* 7–11 (2013).
3. *Design thinking research: measuring performance in context*. (Springer, 2012).
4. *Design, make, play: growing the next generation of STEM innovators*. (Routledge, 2013).
5. Whole Earth Catalog. *The last whole earth catalog: access to tools*. (Craftsman, 1972).
6. Zlotoff, L. Macgyver Television Series. (1985).
7. Dougherty, D. *TED Talk: We are makers*. (2011).
8. Jordan, S. & Lande, M. Additive innovation in design thinking and Making. in *Proceedings of the Mudd Design Workshop IX: Design Thinking in Design Education* 132–140 (2015).
9. Sheridan, K. *et al.* Learning in the making: A comparative case study of three makerspaces. *Harv. Educ. Rev.* **84,** 505–531 (2014).
10. Tweney, D. DIY Freaks Flock to 'Hacker Spaces' Worldwide. *WIRED* (2009). Available at: http://www.wired.com/2009/03/hackerspaces/. (Accessed: 15th December 2015)
11. TechShop. TechShop is America's 1st Nationwide Open-Access Public Workshop **--** What Do You Want To Make at TechShop? (2015). Available at: http://www.techshop.ws/. (Accessed: 15th December 2015)
12. Martin, L. The Promise of the Maker Movement for Education. *J. Pre-Coll. Eng. Educ. Res. J-PEER* **5,** (2015).
13. Rattan, A., Savani, K., Chugh, D. & Dweck, C. S. Leveraging Mindsets to Promote Academic Achievement Policy Recommendations. *Perspect. Psychol. Sci.* **10,** 721–726 (2015).
14. Somerson, R., Hermano, M. & Maeda, J. *The Art of Critical Making: Rhode Island School of design on Creative Practice*. (Wiley, 2013).

15. Maker Media. Maker Faire | Media Kit & Resources - Maker Faire. (2016). Available at: http://makerfaire.com/media-kit-press-resources/. (Accessed: 25th January 2016)
16. Douglas, E., Jordan, S., Lande, M. & Bumbaco, A. Artifact elicitation as a method of qualitative inquiry in engineering education. in 26.235.1-26.235.10 (ASEE Conferences, 2015). doi:10.18260/p.23574
17. Clark-Ibáñez, M. Framing the Social World With Photo-Elicitation Interviews. *Am. Behav. Sci.* **47,** 1507–1527 (2004).
18. Harper, D. Talking about pictures: a case for photo elicitation. *Vis. Stud.* **17,** 13–26 (2002).
19. Geertz, C. *The interpretation of cultures: Selected essays*. **5019,** (Basic books, 1973).
20. ABET. Criteria for Accrediting Engineering Programs. (2014).