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Making People and Projects: Implications for Designing Making-Based Learning Experiences

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Introduction

The objective of this paper is to introduce considerations for designing open-ended, hands-on Making-Based Learning (MBL) educational experiences. The aim is to build upon the authors' ongoing research projects that are seeking to understand the educational pathways of Adult Makers and Young Makers to support undergraduate engineering student coursework and learning. We want to bring these findings from research to practice, in an immediate and practical manner, to those responsible for engineering studios, prototyping labs, and other academic makerspaces. By summarizing and applying our ongoing qualitative work in understanding Adult Maker and Young Maker educational pathways,[1-4] we distill a working framework for designing Making-Based Learning experiences for student learners. This work is foremost on people who Make, are in the process of learning, and participate in a community of practice[5,6].

While opportunities to nurture one's interest in Making and tinkering are growing, the means to foster divergent creativity in the classroom are limited due to real and practical constraints. Hands-on building experiences are becoming less available in K-12 schools and engineering science is a more established introductory approach to teaching college students than human-centered design. Making may provide a new model for progressive, student-centered learning that can match calls from industry for a scalable educational framework that encourages innovation and entrepreneurship among students. Making can be a potentially revolutionary learning platform, with a unique blend of technological and interpersonal skill development and its applied context.

Research Focus and Methods

We are specifically interested in using our ongoing work to address "how the attributes of Making might translate to an engineering classroom context?" The basis for proposing such guidelines for Making-Based Learning is in the synthesis of our findings from a broader, ongoing multi-year set of qualitative research studies exploring Making, pathways of Making, and Making within engineering education[1-4]. We summarize emergent themes from our ongoing work alongside examples collected from Makers, with examples from our respective experiences teaching engineering.

Over the last four years, at flagship Maker Faires in New York City and the San Francisco Bay Area, our research team has conducted qualitative, semi-structured interviews of 42 Adult Makers and 2 dozen Young Makers and parents, the latter of which is still ongoing. Participants are purposefully stratified across age, demographic, and years making, formal or informal engineering education experience, and engineering-related careers or hobbies. Makers participated in artifact elicitation interviews,[7] based on the method of photo elicitation[8] on site, and critical incident technique interviews[9] via Skype. These studies are using a thematic analysis[10] based in a constructivist grounded theory[11] framework. Several times throughout the studies (in iterative cycles), members of the research team have conducted an inductive thematic analysis on the transcribed interviews (generating theory from the data), which fed back to inform questions asked in the interview protocol. The results from individual inductive analysis were triangulated with a deductive coding of the data. This triangulated theory, inductively grounded in data and deductively connected to literature, describes a Maker community philosophy and helps inform improvements for formal engineering education.

Maker Theory: Additive Innovation

Largely, we are developing a theory illuminating the knowledge, skills, and attitudes of Adult and Young Makers, and describing their pathways in pursuing advanced STEM education and careers. This research helps to illustrate the similarities and differences between the activities of Making and everyday practice of engineering. In our work so far, we have identified that participants actively practice "additive innovation,"[1] where they contribute to open communities of sharing and learning. Citizenship in the Maker community means additively building on the work of others and freely sharing knowledge and processes back with the community. The Making community is an "additive innovation network," both as a social and intellectual community. More important than the creation itself is the act of building an artifact and sharing the story of its construction with the Maker community. Makers demonstrate attributes included in the Engineer of 2020[12] – lifelong learning, practical ingenuity, and creativity – through the act of Making itself and through their contributions to additive innovation networks.

Many characteristics of "additive innovation"[1] describe the practices of open sharing and learning present in the Maker community and, through cross-pollination in academic Maker spaces, could grow in the engineering education space. Introduced by the authors as an umbrella concept, "additive innovation" is a mode of collaboration where participants in a community are:

1. inspired by shared artifacts/ideas
2. openly share (and learn about) technology and processes used to create artifacts/ideas
3. design and prototype own modified version of the shared artifact/idea, and
4. shared their modified artifact/idea back with the community

While sharing and re-sharing is prevalent in the Making community, sometimes barrier issues like intellectual property and concern for one's ideas can create an atmosphere of "subtractive innovation" for the engineering classroom. We seek to use examples from Making-Based Learning and examples from the engineering classroom to take our research efforts to inform educational practice and discussions about the future of engineering pedagogy.

Motivation

Traditionally, engineering design is taught as discrete curricular experiences.[13] In many undergraduate curricula it is mostly a means for students to synthesize their engineering content knowledge in capstone courses. These design courses are usually successful, in that the students come up with innovative solutions, are satisfied with their school experience, and feel ready for the real-world. But, what have they actually learned about solving ambiguous problems and integrating Making into their design thinking, engineering doing, and the design process? What does it mean to learn Making? Does the student's own understanding of the engineering design process improve as a result of such experiences? Many engineering faculty report on “cool stuff” they do in class in support of learning but few bolster their reports with evaluations of the student learning or ground them in prevailing cognitive science or educational psychology.[14] With our ongoing work, we aim to work towards understanding the cognitive process in Making and propose a framework of and assessment for learning. The aim is more effective teaching. It can also add a facet of diversity when forming student and industry teams. It can suggest a shared approach to multi-disciplinary collaborations.

Engineers participate in the Maker movement. Some Makers do not pursue formal engineering education but both the engineering field and their own vocational advancement could readily benefit. With our ongoing research into understanding Adult Maker and Young Maker educational pathways,[1-4] we seek to understand Making and how Making activities and work are inclusive or exclusive of what we expect from engineers and engineering students. From the NAE “Engineer of 2020” report,[14] we highlight practical ingenuity, creativity and lifelong learning for likely opportunities to leverage the Maker experience. With an ultimate goal of facilitating more effective teaching and learning of Making through the experience of learning engineering and design in the undergraduate engineering classroom, we build on a list of qualities that have emerged from our previous Making-related work and place in the context of undergraduate engineering education. We share these learning attributes below with examples from Making and engineering, and how it may become reflected in the engineering classroom in the future. This makes for an opportunity to further bolster relevance and context for the instructor and the student learner.

What is a Maker?

A Maker undertakes projects of personal meaning, sometimes without prior expertise, generally resulting in the creation of technical artifacts. The label Maker is a self-determined one assigned by affinity or involvement in a larger Making community. *Make:* magazine is a central participant in championing making,[15] celebrating people engaged in Making as well as starting Maker Faires. Different intellectual communities have focused on different aspects one can relate to Making. The human-computer interaction field has studied hacking and tinkering in the context of DIY and tools and practices[16,17]. Design research has examined ad-hoc prototyping and tinkering using artifacts[18]. Flexible space for activity are growing in popularity and use with hacker spaces[19] and Maker spaces and fab labs.[20] A Maker[21-25] is an emerging colloquial term we use to describe a group of do-it-yourself minded individuals participating in informal communities (doing-it-with-others) that support and celebrate prototyping technical proof-of-concept exploration and ad-hoc product development. The range of Makers’ expertise could be large, but novices and experts alike share an enthusiasm for creating the additive innovation philosophy.

Learning Attributes of Making

Making is rooted in constructionism – learning by doing or Making and constructing knowledge through that doing.[26] Aspects of Making that could appear in the engineering classroom are described in the following sections. Attributes of Making come directly from themes emerging from our ongoing research[1-4, 21-25] listed in Table 1.

Table 1: Attributes/themes of Making and common definitions[1-4, 21-25]

Sharing	give jointly
Practical ingenuity	of doing, quality of cleverness
Personal investment	of one, commit money
Playful invention	amusement, creative abilities
Risk taking	danger, application
Community building	group of people, constructing
Self-directed learning	initiative, knowledge to acquire

This work builds on our ongoing efforts to understand the educational pathways of Adult Makers and Young Makers in the wild. Previous publications have described these efforts, inclusive of our methods, and knowledge and skills Makers demonstrate[1-4, 21-25]. The focus of this paper is to provide categories and details for Making-Based Learning that can be relevant in the classroom.

Sharing

Within the Making community, knowledge distribution takes places in several different ways and with different configurations of knowledge providers and recipients. Makers share both recipes and artifacts (one-to-many) with both other Makers and interested spectators. They celebrate and learn from others' accomplishments, and openly accept criticism to improve their designs (many-to-one). With the advent of online information-sharing platforms like *Instructables* and Thingiverse, project collaboration, evaluation, revision and iteration can be scaled to an indefinitely large population. Examples of doing this within a Making context are reading about a project in *Make:* magazine and building it, or helping others with their projects in a makerspace. An engineering example is an Engineering Projects in Community Service (EPICS)[27] project that continues over semesters (one-to-one) or feedback given to other students at a design review (many-to-one). A key focus of collaborative projects in school settings is to work together within a team towards a shared goal. In many academic learning contexts however, individual work is expected, leaving students to navigate multiple sets of expectations that support collaboration, or consider such activity to inflame concerns about academic integrity via plagiarism or cheating.

Practical Ingenuity

Makers build and prototype using available materials, tinkering through multiple iterations in an agile approach. A Making approach may be illustrated by building solutions first, before analysis, or using advanced manufacturing tools, scavenging through the hardware store bargain bin, or testing incomplete solutions. From an engineering perspective, it might look like troubleshooting when something doesn't work right, scavenging through an engineering lab or purchasing materials, scaffolded prototyping milestones over a semester, or updating assignments based on draft feedback. A key consideration is that building before analysis doesn't align with a traditional engineering process, but does align with a design thinking mindset to prototype early and often. Practical ingenuity is called out in the NAE “Engineer of 2020” report list of attributes for the engineer of the future[12].

Personal Investment

Makers are strongly invested and motivated to work on their projects. They care because they are personally interested in their projects, and take ownership over the solutions they take. This may manifest as making a fire breathing dragon made out of spoons, just because, taking responsibility for building a section of an art car, becoming an expert in 3D printing and sharing that expertise, or designing an LED prom dress for your older sister. In an engineering context, it could look like taking responsibility for a share of the project, doing an all-nighter for an assignment, using a membership at a Makerspace, participating in an engineering related extra-curricular like Baja, or going above and beyond what is required for a project. A key consideration is that rewards like reputation or grades may factor into effort.

Playful Investment

Makers exhibit creativity, novelty, and play in their creations. At times they are inventing a future. Evidence of this might be building with absurdity, like a fire-breathing octopus, communing with like-minded quirky people via the internet, using “alternative energy” to come up with out-of-the-box ideas, or hacking your GE appliances to make breakfast when your alarm goes off. In an engineering space, it could be creating surprise and delight for a user group, applying aesthetic flourishes, brainstorming wild and crazy ideas, with non-yellow Post-Its, or applying a design challenge prompt in form of “design for the future of X.” A key consideration is that play can be seen as frivolous and undermining rigor, rather than an opportunity to convert interest and passion into invention.

Risk Taking

Makers can treat failure as a badge of honor and admission into their community. Makers have the confidence to try creative solutions and learn by doing, failing, and doing again. Something might happen like denting your parents' car while testing a dog entertainment device, taking apart an appliance to see how it works, and having extra parts afterward, trying to solve a problem using a new approach that can't be found on Google, trying to make a fish-controlled robot, discovering that duct tape doesn't hold water, and replacing the duct tape with a peanut butter jar. For engineering, it might be copying from another student's exam, asking questions in class, trying to design/build something that you have never done before, or trying to solve a problem for which the professor has not provided a solution. A key consideration could be that what might be risky behavior for one, might not amount to risky behavior for others. Risk aversion is defined by the individual. Engineers not comfortable with ambiguity, taught to eliminate uncertainty.

Community Building

Makers seek connection with others and operate in shared social communities. Rather than DIY, the Maker Movement is do-it-together. Participation is the (non-exclusive) means for membership. Collaboration is typically without external competition (though lifelong learning is viewed by some as a competition with oneself), and the community retains knowledge. It might also include entrepreneurship, eclectic personalities, high social skills, and networking. It might appear as governance of shared spaces and resources, i.e., running a local Makerspace, participating in outreach events in the community, making a t-shirt for an event or team or wearing a costume themed to match a project theme. In an engineering curriculum, it might be working in teams in a class, forming a study group, sharing your solution to a problem openly without fear of academic integrity violations, or sharing notes with others in a class. A key consideration is that it can be awkward to assess individual learning or performance in a group.

Self-Directed Learning

Makers take initiative to identify what they need to know to achieve their overall goal, find and learn what they need to know from their community (mentors, Makerspaces, Maker Faires, and websites) and apply what they have learned to their projects. That might be something like learning how to integrate Making tools together. For examples, integrating a Kinect camera with an Arduino, receiving a suggestion from a mentor that a laser cutter could be used to create a project enclosure, and learning how to use it to make one, asking another Maker how they made something, and adapting their design to make it "your own," or finding and following instructions on Instructables. For engineering, it could be identifying a misconception and attending office hours to get help, reading the textbook out of interest rather than requirement, asking another team how they solved a problem, and basing your solution on theirs, or Googling the solution to a homework problem. A key consideration is that some lifelong learning and information literacy behaviors are more desirable in academic and professional settings than others. Additional, specific skills related to Making in the context of engineering courses may also include multiple representations, visual thinking, a connection to real world, levels of abstraction, creativity, and application to engineering content.

Future Role for Making in the Classroom

There is an opportunity to connect engineering Making and doing to undergraduate engineering curricula. Making-Based Learning can support students in academic Makerspaces. It is also a potential magnet for attracting and recruiting a broader base of engineering students. An inversion of the values of engineering analysis and engineering doing may be necessary to fully and authentically support the role of Making in the classroom. At the very least, it is possible to imagine engineering curricular reform and support for active and project-based learning wrapped up in Making-Based Learning.

A new frontier in the engineering education community is the study of Makers, Making and Making-Based Learning. It obviously fits into some aspects of the engineering curriculum, such as first-year Introduction to Engineering courses and project courses in programs with a project spine (e.g., Arizona State University, Harvey Mudd College, Olin College). However, engineering faculty critics of the Maker movement argue that Makers do not actively learn and apply engineering fundamentals in their projects, thereby limiting the applicability and appropriateness of Making-Based Learning pedagogical techniques in the engineering curriculum.

We aim to broaden the discussion by introducing attributes of Making drawn from qualitative research on the Maker movement. Desirable outcomes of applying Making to the engineering classroom are introduced. This paper can prepare readers to engage in a deeper discussion with their faculty to add Making to engineering courses, providing new language, examples and key considerations for doing so. Makers seem to do engineering, engineering students do not necessarily Make. We seek to change that.

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