International Journal of Engineering Education Vol. 34, No. 2(B), pp. 833–842, 2018
Printed in Great Britain

0949-149X/91 $3.00+0.00

The Engineer of 2020, in the Making: Understanding how Young Adults Develop Maker Identities and the Implications for Education Reform*

STEVEN WEINER
School for the Future of Innovation in Society, Arizona State University, 1120 South Cady Mall, Tempe, AZ 85287.
E-mail: Steven.Weiner@asu.edu

MICAH LANDE and SHAWN JORDAN
The Polytechnic School, Ira A. Fulton Schools of Engineering, Arizona State University, 7171 E Sonoran Arroyo Mall, Mesa, AZ 85212.
E-mail: Micah.Lande@asu.edu, Shawn.S.Jordan@asu.edu

Making is a social phenomenon that encourages the adoption of many of the practices, skills, and knowledges associated with STEM (Science, Technology, Engineering, and Mathematics) disciplines. It also incorporates many of the key personal attributes of the Engineer of 2020. Although educators have started to institutionalize this connection through the establishment of makerspaces and Maker-based curriculum, less effort has been made to understand how the current population of "grassroots" Makers have come to identify with this movement. In this qualitative research study, we analyze critical incident interviews of young adults who frequent shared-use community workshops, or makerspaces. Employing a theory-driven thematic analysis, we developed an initial process framework for Maker identity formation that could provide educators with a useful perspective when implementing Maker-based programs in their institutions.

Keywords: Maker Movement; identity formation; STEM education reform, future engineers

1. Introduction

Since the publication of the *Engineer of 2020* report in 2004, cultural and technological change has dramatically altered the conversation about the future importance of STEM education. The democratization of digital fabrication technologies such as 3-D printers, explosion of Internet-based knowledge-sharing platforms like Pinterest, and reemergence of the DIY (Do-It-Yourself) ethos all have combined to give rise to new pathways for mastering 21st-century skills and knowledge [2], particularly through the social phenomenon known as the Maker Movement. Amateur and professional artists, scientists, engineers, educators, designers, and inventors have gathered around the banner of "Making" [3] to celebrate qualities like practical ingenuity, creativity, and lifelong learning—some of the key attributes noted as essential for the engineer of the future [1]. Educators advocate that young adults who self-identify as "Makers" will become our future STEM majors and engineers [4] who will invent the future.

Educators often cite the young Makers' failure-positive mindset, grit, and self-motivation [5] as rationale for introducing Maker practices into their schools, classes, and extracurricular activities [6], in addition to their expertise with specific tools and technologies. Efforts to reform curricula around Maker practices, Maker clubs, and convert libraries into makerspaces have increased at a rapid pace [7]. The underlying assumption is that these efforts are accurate translations of Maker practices which will increase interest and success in STEM learning, thus better preparing students to become scientists and engineers. While this may be true, little research has been done that directly suggests that opening a makerspace or introducing a Maker class or club will actually achieve these ends. This study refocuses attention on young adults who already identify as Makers to understand how their experiences leads to the development of their Maker identities. This may provide educators with valuable insight on how to cultivate similar qualities in their students and to reframe the engineer of the future.

1.1 The Maker Movement and author subjectivities

We believe that, as a source of pedagogical and philosophical inspiration in education, the Maker Movement has incredible potential to transform the way that we think about both formal and informal education. While significant and valid critiques have been made concerning issues of privilege, equity, and inclusion within Maker activities [8, 9] we believe that these issues are artifacts of the institutions in which they exist rather than inherent to Maker activities themselves. By conducting research to further understand these activities and the factors that led to their adoption by young

* Accepted 12 January 2018.

Makers, we believe that this will support larger Maker implementation efforts that seek to diversify and promote equity within institutionalized educational settings. Furthermore, the fact that Making is a privileged activity does not diminish its value to those who participate, nor does it lessen the possible value for those who may be excluded. Like Lindtner, Bardzell, and Bardzell [10], we also hope to "take serious the critiques of making's claims . . . while also embracing its utopian project as worth reconstituting in broader sociopolitical terms".

1.2 Teaching and learning in the Maker Movement

The Maker Movement has been framed in a myriad of both intersecting and divergent ways: as a reaction against consumer culture [11], a pathway to increasing innovation and economic growth [9–11], a mindset encouraging personal engagement with technology [15], a community of hobbyists who build whimsical contraptions [16] , a philosophical creed that defines the critical aspects of our humanity [4], and a way to empower individuals to solve technical problems that traditionally reside in the domain of experts [17]. Underlying this range of ambiguous aims and goals is a set of overlapping social interactions and practices centered on the sharing of knowledge and skills pertaining to the construction or modification of physical objects. These interactions take place through websites like Instructables and Adafruit [18], at community workshops, often called makerspaces [19], and at local festivals generally run under the brand name Maker Faire, owned by the Maker Media company [16].

Jordan and Lande [11, 17] termed the iterative process by which Makers share knowledge and improve upon each other's works as *additive innovation*. Given that the individuals taking part in cycles of additive innovation learn to utilize advanced tools and technologies, complete complex projects, and often design working solutions to real-world problems, it is no wonder that the Maker Movement is now perceived as a vehicle for improving STEM education [21]. However, efforts to import Making into formal educational institutions have thus far seen limited success in fostering cultures of additive innovation within the context of traditional class structures.

1.3 Translating Making into formal education

In response to longstanding calls for educational reform [19–21], educators and administrators have started to look toward Making as a source of positive change in both the K-12 and higher education arenas [25]. Despite criticism about Maker Media's role in shifting the Maker Movement toward corporatization and commoditization [9, 26, 27], Maker Media CEO Dale Dougherty can be credited for taking an early lead in fostering conversations between Makers and educators, largely through the work of the Maker Ed non-profit organization [28]. Educators and scholars have picked up the mantle by drawing explicit connections between Maker practices and the existing pedagogical theories of Dewey and Papert [29] as well as increasingly-popular teaching strategies like Project-Based Learning (PBL) and design thinking [30–32]. These connections [33], while helpful in generating credibility about the educational value of Making, have only catalyzed limited changes, largely centered on the creation of makerspaces.

Along with Maker Faires, makerspaces are one of the most visible manifestations of the movement and, like the movement itself, the definition of a makerspace is diffuse. Makerspaces take a wide variety of shapes, sizes, from single rooms in church basements [19] to seven-story buildings on college campuses [34] to retrofitted charter buses [35]. Generally, they contain a wide variety of tools and materials ranging from high-tech digital fabrication equipment to traditional power tools, metal and woodworking machinery, as well as art and textile supplies. They also are designed to encourage socialization and collaboration, often taking on flexible space designs with multiuse and moveable furniture [36]. Makerspaces initially emerged as a variant of hackerspaces, which are co-working spaces operated by computer programmers looking to share ideas and collaborate with peers [37]. While hackerspaces are generally grassroots organizations, fully operated and maintained by the community that uses them, the makerspace model has been adopted by a wide variety of institutions, including museums, libraries, research universities, and for-profit corporations in order to support their organizational goals (e.g., increasing attendance, employee retention, innovation, etc.).

The proliferation of makerspaces in schools constitutes the greatest proof of impact from the Maker Movement on formal education. Yet, the notion that Making is primarily a set of technical skills or STEM-related knowledge, such as using a sewing machine or designing digital models for 3D-printers, diminishes its strongly social and philosophical [4, p. 11] elements. While not eschewing the value of these spaces, we hope to broaden the scope of the conversation and shift the attention away from the processes of Making and onto the development of the identities of Makers themselves.

1.4 Identity and the formation of Makers

A great deal of research has been conducted at the intersection of identity and education [38, 39]. Most studies addressing STEM education focus on pro-

fessional identities, such as those of scientists or engineers [40–43], or are primarily concerned with gender or cultural identities [42, 43]. In a previous study [46], we argued that the centrality of identity to the Maker Movement made it an intellectually-fruitful area for scholarly inquiry as well as potentially helpful in improving efforts to translate Making into schools.

Flum and Kaplan state that identity "is a key concept in the social sciences in general and a term that captures a variety of nuanced meanings" [38]. Like the wide array of definitions of the Maker Movement, identity is both ambiguous and rich in significance. In much of identity literature, two critical dichotomies arise: one being the tension between individual agency and social context as defining one's identity [38] and the other being the conception of identity development as a series of discrete and sequential "statuses" as opposed to a continuous narrative [39].

In searching for an appropriate theoretical perspective for our previous study [46], we sought out a framework that would emphasize the social aspects of identity, making it useful in both the context of educational and Maker practices. We also looked for a framing that would allow for the discrete parsing of underlying factors or perceived reasons that young adults see themselves as Makers. For these reasons, we employed Gee's identity lens framework [47].

Gee takes the position that "being recognized as a certain 'kind of person,' in a given context, is what I mean . . . by 'identity.' In this sense of the term, all people have multiple identities connected not to their 'internal states' but to their performances in society" [47, p. 99]. In other words, an individual can maintain multiple identities, even at the same time, depending upon their social environment. He lays out four independent analytical lenses: Nature, Institutional, Discourse, and Affinity, which can span from more ascribed, or externally-given, personal traits to more achieved, or individually-earned, characteristics. For example, if a young Maker described their initial interest in soldering as due to doing a particular project in a class, this would be indicative of an Institutional identity; if they said it was based on being part of a supportive, interest-driven soldering group, such as can be found within the Making community, then that would be an Affinity identity.

Through the application of Gee's identity framework, we devised and conducted a deductive study of young adults who presented their creations at large flagship Maker Faires. We found that Maker's exhibit certain characteristics that were not fully captured by the original framework, and this necessitated the creation and modification of several categories (see Fig. 1; See Appendix 1 for full descriptions of these categories). Most notable was the addition of a Material Discourse-identity, which focused on Makers' rapport with tools and materials, and Relational-identities, which is characterized by the influence of friends and family who encourage Making.

This study left us with significant questions about the relationships between these categories. Why did young Makers describe their experiences through different lenses at different times in their life? Did their narratives suggest a progression of identity "statuses" that moved between these lenses? This line of inquiry led to the current study.

2. Methods

2.1 Research purpose

To improve the process of translating the key elements of the Maker Movement into institutionalized educational programs, further research is needed that focused on the process by which young adults develop a Maker identity. Thus, our main research question is: *In what ways do the underlying factors and experiences of young Makers illuminate a process (or set of processes) of Maker identity formation?*

2.2 Research design

Starting with a modified version of Gee's identity framework [46], we conducted a theory-driven the-

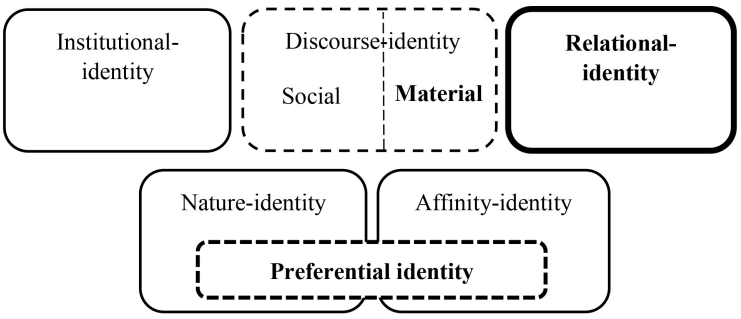

Fig. 1. Gee's Identity Lens Framework, modified for Makers [46] (bolded elements indicate additions, dotted lines indicate changes).

Table 1. Chart of participants' self-described "Maker" characteristics

Name*	Age	Gender	Years as a Maker	Areas of Interest	Technical Skills
Alex	13	Male	5	Jewelry-making, art	Working with resin and wood, Corel
David	21	Male	7	Live-action role playing, robotics, large art pieces	Electrical/circuitry, woodworking, prototyping
Aaron	15	Male	3	Interactive games, writing, lighting	3D Printing, CNC Machining, 3D/CAD design, woodworking

* Pseudonyms.

matic analysis of semi-structured interviews with three self-identified young Makers. While the *a priori* theory was used to drive the interview protocol design, the codes were derived inductively from the data [48]. As noted above, we utilized a modified version of Gee's original framework that was amended and expanded to account for Maker-specific identity types derived through a previously-completed research study of young adult Maker Faire participants [46].

2.3 Data collection

Data for this study was gathered using semi-structured critical incident interviews [49] from three young adult Makers who frequent two makerspaces in a large metropolitan city in the Southwest. Critical incident interview protocols attempt to gain insight into participants' perceptions and beliefs by asking questions centered on significant and meaningful experiences. Since Makers are often engaged in discrete projects or competitions, critical incident interviews were an appropriate way to understand the formation of their Maker Identity. Examples of the questions are: *What was the most important thing that helped you become a Maker?*, *What would you say was the most meaningful/memorable project you have done*, and *Can you tell me about when you first started to think of yourself as a Maker?* While the interview protocol was designed to elicit answers related to each of the identity types, the semi-structured that allowed for greater variation in responses.

We coordinated with the administration of two local makerspaces to connect with the participants. Two of the interviews were conducted in a quiet, private room on a makerspace premise; the third was conducted using an Internet-based video conferencing program.

2.4 Participant selection

The first author was familiar with several communities of young Makers through his roles as an informal science educator and an academic researcher. We purposefully sampled [50] three specific young Makers who illustrated a wide range of ages, areas of interest, and technical skills that occur within these Maker communities [51]. Table 1 shows some of the participants' key traits, gathered from their questionnaire responses.

Two of the participants were brothers, ages 13 and 15, and frequented a makerspace which was part of a larger public informal science education institution. The third participant, age 21, utilized a makerspace on a college campus. Both spaces provide students with access to similar kinds of tools, materials, and workspaces, with some restrictions for youth under the age of 13 at the public-access space. The interviews ranged from 22 to 60 minutes. Parents of the minors, while not part of the interviews, were required to complete a consent form; the young Makers were also asked to complete an assent form which provided the same information.

2.5 Limitations

This study used qualitative research methods and a small sample size, and thus the resulting themes and theory should be considered as generative of hypotheses and future research questions, and not generalizable conclusions. While the three participants did vary in the areas of age, interest, and technical skills, all were male and white. Future research will include more participants and an additional site will hopefully allow for the chance to include a broader range of young Makers, specifically regarding gender, race, and socioeconomic background. While we hope to improve the diversity of our sample in future work, we also believe that small population size does not limit the value of the qualitative knowledge gained [52]. Given that the participants in this study engage in practices and hold beliefs that are uncommon within their demographics, they constituted a valuable source of insight and information.

2.6 Data analysis

The transcripts were coded using Dedoose, a web-based qualitative data analysis program. The major themes of this study came out of a coding process which evolved throughout the project. In the initial

stages, identity categories from Gee's modified framework were deductively applied to the interview texts, while simultaneously allowing for additional codes to emerge inductively. While this approach does admit for limitations in potential codes, the strategy of negative case analysis [53] was employed to validate the modified framework.

Through the first pass of coding, it became obvious that allowing more granular, inductive codes to emerge was more a productive way to understanding the young Makers' experiences. In the second pass, codes were pared down and collapsed into groups, keeping the identity categories in mind. Towards the end of this phase, we revisited the identity categories and considered their relationship and alignment to the identity framework. It was through the process of reflecting on the connections between the emergent codes and the deductive categories, along with further refinement of the codes that the key themes emerged.

3. Results

Three of the four main themes of this research are best understood chronologically, as they sketch out the participants' journeys towards the adoption of a Maker identity[1]. These themes coalesced around codes that connected or straddled two or more of the identity categories. The final theme addresses the weak relationship that most participants saw between formal education and Making.

3.1 Making before being a "Maker"

All three participants indicated that they had been making long before they developed identities as Makers. Aaron said that "since I was six, I just built Legos®, like any kid I built Legos®", although he qualified this as not "seriously" Making. Alex also downplays his experiences with art, suggesting that having "gotten into sketching with my hands" was related to Making, but did not count as an 'official' Maker activity.

Generally, the participants described their first experiences with hands-on crafts or Maker-related activities as taking place when they are young and frame these situations through Relational or Preferential/Nature-identity lenses. David describes his parents as providing opportunities for both making and "breaking" things when he was younger. "A lot of kids had video games growing up. My parents handed me a hammer and said, 'there's a bunch of rocks in the backyard, have fun.' I found crystals inside the rocks and I had tons of fun with a little mine that I built." Around the age of ten, David took apart a remote control car in his parents' basement and describes how they supported his natural curiosity:

> "When my parents came down . . . there were just parts of things laying on this table because I had been taking apart everything I could get my hands on, that I knew I could get away with taking apart. They were at first, just kind of like, 'What a big mess.' Then they were like, 'okay, he's just trying to learn.' They started labeling stuff, like, 'don't take this apart. You can take this apart but don't take this apart.' "

The young Makers described more in-depth interactions with specific tools and materials at older ages, constituting a transition to the Material Discourse-identity. Aaron spoke at length about his evolving interests in equipment that incorporates digital design with hands-on building and described how these interests reflected his understanding of his own predisposition towards certain skills and activities. Alex, who is younger than his brother Aaron, talked in detail about his experiences with woodworking and resin-casting, though indicated that he was still exploring other crafts. Conversely, David, six years older than Aaron, dwelled less on describing specific technical practices and talked more about his broader goals and motivations for making. These differences may hinge around the timing of each individual's adoption of a Maker identity.

3.2 Meeting the movement

Before fully self-identifying as Makers, the participants indicated an additional identity "phase", in which they connect with peers or mentors with similar interests, thus bridging between their Material Discourse-identity and an emerging Social Discourse-identity. Both David and Aaron mentioned Maker-based competitions as significant pre-Maker experiences, while Alex noted his participation in a Maker summer camp. In each of these instances, the participants engaged simultaneously in both social and material discourses, fostering a core practice of the Maker movement, collaborative problem-solving and prototyping.

Working with influential mentors was another significant kind of experience which blended the social and material discourses. David described in detail his experience working with a supportive and knowledgeable art teacher who spent time out of class helping him build a dragonfly sculpture out of found materials. David concludes this story by saying that:

> "It really showed me that I could build stuff for enjoyment. I hadn't really built things, I'd just taken things apart up to that point because I didn't really

[1] In this study individuals are said to possess a "Maker identity" if they see and refer to themselves as a Maker. This does not preclude the possibility that there are multiple kinds of Maker identities or that individuals may conceive of these identities in different ways.

> have many tools to work with. I finally had the tools to work with and the mentorship and so that was one big event for launching me into Making was actually making something."

Another milestone for each of the young Makers was their attendance at their first Maker Faire. All expressed feelings of awe about these events. For brothers Aaron and Alex, it was through meeting a nationally-recognized young Maker that acted as a major inspiration for them to become active in the Maker Movement. Aaron says that:

> "It was the first Maker Faire I've been to and I met this kid there . . . you might've heard of him [as a well-known young Maker] . . . he brought us over to his house, showed me how to solder and that was just huge for me."

Aaron and Alex both cite this experienced young Maker as one of the influential mentors that welcomed them into the social world of Making.

3.3 Bearing the standard of Making

After recognizing themselves as Makers, the young adults displayed evidence of Affinity-identity, which is typified by a group's collective engagement in practices and activities based on shared interests. All participants were happy to be associated with the Maker Faire organization, some even owning Maker Faire t-shirts or displaying other accessories, though none of them felt so strongly about identifying as a Maker that it necessitated the exclusion of other designations, such as artist or engineer. Once connected to a larger Maker community of practice, the participants looked for ways to continue sharing, making, and collaborating with like-minded peers. They attended more Maker Faires, or other similar festivals, and sought out makerspaces in the local area for access to specific tools and to meet other young Makers.

The previously-developed identity lenses continued to be utilized by the young Makers even after achieving an Affinity-identity, though they often appeared in different forms. Aaron, who spoke highly of two peers who mentored him in his Making endeavors, has become a mentor for several teenagers through Maker classes for homeschool students. Alex has also transitioned from just "messing around" with a variety of materials and techniques to planning to start his own online store for his art and jewelry. The way he talked about his interest in creating unique wood-resin hybrid creations suggested the employment of a sense of agency and personal ownership that relates to the Preferential-identity; this stood in contrast to the seemingly-related Nature-identity, which was invoked to describe early-childhood experiences.

3.4 An absence of "Institutional Makers"

Throughout all three conversations, a strong relationship between formal educational or professional Institutional-identities and Making were extremely limited. In most cases, the young Makers rejected the notion that formal education could be a place to develop a Maker identity. Alex and Aaron both cited their experiences as mentors with a homeschool group as proof that Making is challenging to do in a classroom setting. Alex captures some of the real tension between schooling and Making when providing this advice to teachers who bring Making into their classrooms: "make sure [the kids] are on what they're making, what they're supposed to do, but let'em be free on what they're doing."

David suggested that the larger issue would be a lack of student motivation:

> "If you say, 'Pick your own fun project,' half of them are going to be like . . . 'I got nothing. What do you want me to do?' Even my college roommate a little bit is like that. With software, he doesn't really do software projects for fun. So when I try to do stuff like that he just like, 'Tell me what I need to do. Just give me the criteria I must meet and then I'll do it, and that is that.' "

He goes further in contrasting his perception of Engineering identity with that of Maker identity:

> "A lot of engineers are kind of like that too. So, I don't think a class would go over well because of a lot of them just aren't motivated to do it. That's where I think a club is the better way to go about it because then people who are really like, 'I want to do this,' then they find out about the club, then they go to the club, then they can do it."

While Aaron suggested that his projects were examples of engineering, he felt more comfortable thinking of himself as an entrepreneur. David and Aaron both contrasted the label of "engineer" to Maker, David saying at several instances that his training as an engineer has at times conflicted with his pursuits as a Maker, though at other times was somewhat in alignment. The presence of such strong sentiments about the difficulties of having institutionalized "Maker" identities serves as a useful jumping off point for the larger discussion about this study's implications.

4. Findings

The results from this analysis suggested that the modifications made in our previous study of Gee's identity lenses proved robust for parsing the data from the updated interview protocol which was designed specifically to explore Maker identity. At the same time, the data also provided significant clues to the relationships between these lenses and,

as discussed below, an initial process model for Maker identity formation emerged.

4.1 An "embedded lenses" process model

During the data coding process, the language of "phases" and "turning points" emerged as useful for explaining the shifts between certain identity lenses. The fact that the young Makers displayed similar trajectories through the identity lenses suggested that there may be a progression or ordering to forming a fully-realized Maker identity. Initial visualizations of this process were linear and discrete stages, similar to Marcia's elaboration of Erikson's identity status model [54]. Yet, further analysis of the data revealed that the young Makers we interviewed displayed the ability to return to identity perspectives that had already been developed, and often moved back and forth between two or more lenses. For example, Material and Social discourses seemed to be extremely recursive with one enabling the development and refinement of the other, even though the Material Discourse-identity had to be established, at least minimally, before the Social Discourse-identity can start to develop.

In short, what emerged was not a sequential model, but instead a nesting of the lenses (Fig. 2). While the smallest or most interior lenses are the "starting" points, they are not left behind as an individual's Maker identity matures, but instead can be revisited. It seems appropriate to interpret this progression from the Nature and Relation-identities, which are ascribed by external forces and factors (like relatives, friends, or one's own preferences) all the way out to the Affinity-identity which is solely maintained by an individual's sustained and intentional commitment to a set of practices that they personally understand and appreciate. Gee mentions the difference between ascribed and achieved identities; this model suggests that the Makers actually move from the former to the latter in building their Maker identity. It is interesting to note that this model irretrievably spilt the Preferential-identity into two parts, which were subsumed into the smallest and largest categories. More research should be done into the nature of preference, but the data suggested that there was a qualitative difference between a young Maker appealing to their inner nature with statements like "I have always liked doing art" versus an Affinity-based preference, which would be more detailed and exhibit a stronger sentiment.

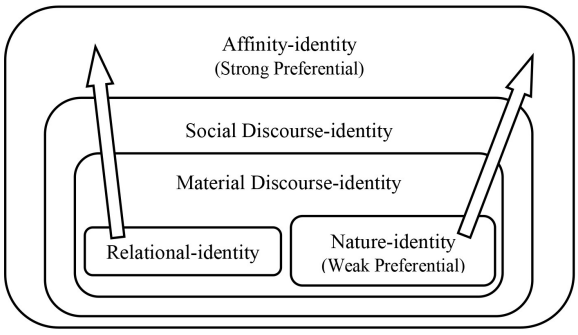

Fig. 2. An "Embedded Lenses" Process Model for Maker Identity Formation.

4.2 Fostering institutional maker identities

The skepticism of our young Maker participants regarding the challenges of translating Making into the classroom is reinforced when considering the resulting identity process model in comparison to the aims and goals of a traditional school. Fostering an achieved Affinity-identity requires deep personal commitment, intrinsic motivation, and long-term socially- and materially-connected discourses. The curriculum-centered design of most classes relies on impersonal assignments, extrinsic grading schemes, and short-term assessment goals. Yet, it seems possible to imagine a class or curricular structure that seeks to create environments and experiences guided by a process of identity expansion and designed to help shift students from identities which are more ascribed to ones that are more independently achieved.

The first expansion may be implemented through mentorship with Makers. It might be less challenging or costly than building a makerspace to simply provide time and opportunity for students to work with inspiring, Maker-oriented adults or peers that could help them forge a bond with a particular skill or craft. Mentorship and freedom to explore their own interests, especially at the elementary and middle school levels, may go far in setting the foundation for the development of the more achievement-based identities. In this school, administrators and teachers would be deliberate about encouraging the formation of peer-based working groups that may coalesce around specific kinds of Making or perhaps different problems. These may look like existing project-based learning configurations, though would be predicated upon a deep understanding of specific tools and an ability to self-motivate and self-direct. As these students progress to embracing their unique interests, skills, and passions, they then should be encouraged to act as guides for younger students or for their peers who may have developed different areas of interest. This iterative cycle transforms Making from an isolated mindset or set of skills into an identity and a culture.

While specific pedagogical frameworks or makerspace-based tools may provide educators with the ability to cultivate technical skills and more creative, iterative thought processes in their students,

these efforts seem to miss the crucial element of Maker identity. Rather than focus on the acquiring of technical skills like 3-D printing and CNC milling, or self-motivated, growth mindsets [55], the findings of this study suggest that young Makers developed their identities thanks to the presence of committed mentors, opportunities to explore their passions and hone skills in social groups, and immersion in positive and collaborative cultures. Put another way, young adults develop Maker identities not based on the novelty or inherent value of a particular technology or set of skills, but instead through social and material discourses.

We might consider then that the traits of the future engineer, such as being collaborative, communicative, and flexible, might be most productively developed not in traditional classes, but rather in a kind of "learning ecology" [56] that takes structural cues from project-based learning curricula [57], emphasizes the iterative nature of design thinking pedagogies [14], and employs an "Embedded Lens" model as a guide and benchmark for student identity development.

5. Conclusion and future work

Going forward, we are left with questions about the practicality of implementing such programs in school settings. With the great inertia of educational institutions toward standards-based testing, how might these changes come about? Given that the notion of a learning ecology spans the divide between informal and formal education, perhaps community makerspaces could act as partners to traditional schools and help instill their social practices and values into the educational institution's culture. What would be the effect of such a partnership on the students, teachers, parents, and administrators of a traditional school? How would it effect their perception of the goals, processes, and priorities of formal education? These avenues of inquiry beckon towards future studies and are suggestive of the wide range of possibility open for exploration at the intersection of Making and education reform.

Acknowledgements—This material is based upon work supported by the National Science Foundation under Grant No. 1329321. We thank the professors and fellow students from Arizona State University Engineering Education Systems and Design PhD program for providing guidance, feedback, and encouragement during this research project. We are also grateful for the participation of our research participants.

References

1. National Academy of Engineering, Ed., *The engineer of 2020: visions of engineering in the new century*, Washington, D.C: National Academies Press, 2004.
2. K. Peppler and S. Bender, Maker movement spreads innovation one project at a time, *Phi Delta Kappan*, **95**(3), 2013, pp. 22–27.
3. D. Dougherty, T. O'Reilly and A. Conrad, *Free to Make: How the Maker Movement is Changing Our Schools, Our Jobs, and Our Minds*. North Atlantic Books, 2016.
4. M. Hatch, *The Maker Movement Manifesto: Rules for Innovation in the New World of Crafters, Hackers, and Tinkerers*, 1st edition. New York: McGraw-Hill Education, 2013.
5. J. Remold, J. Fusco, K. Anderson and T. Leones, *Communities for Maker Educators: A Study of the Communities and Resources that Connect Educators Engaged in Making*, SRI International, Menlo Park, CA, 2016.
6. M. Honey and D. Kanter, Eds., *Design, make, play: growing the next generation of STEM innovators*. New York, NY: Routledge, 2013.
7. N. Lou and K. Peek, By The Numbers: The Rise Of The Makerspace, *Popular Science*, 23-Feb-2016. [Online]. Available: http://www.popsci.com/rise-makerspace-by-numbers. [accessed: 05-Dec-2016].
8. A. L. Toombs, S. Bardzell and J. Bardzell, The Proper Care and Feeding of Hackerspaces: Care Ethics and Cultures of Making, in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, New York, NY, USA, 2015, pp. 629–638.
9. S. Vossoughi, P. K. Hooper and M. Escudé, Making Through the Lens of Culture and Power: Toward Transformative Visions for Educational Equity, *Harv. Educ. Rev.*, **86**(2), 2016, pp. 206–232.
10. S. Lindtner, S. Bardzell and J. Bardzell, *Reconstituting the Utopian Vision of Making: HCI After Technosolutionism*, 2016, pp. 1390–1402.
11. D. Dougherty, The Maker Movement, *Innov. Technol. Gov. Glob.*, **7**(3), 2012, pp. 11–14.
12. C. Anderson, *Makers: The New Industrial Revolution*, Crown Business, 2014.
13. M. Muro and P. Hirshberg, Five ways the Maker Movement can help catalyze a manufacturing renaissance, *Brookings Institution*, 04-Jan-2017.
14. S. Jordan and M. Lande, Additive innovation in design thinking and making, *Int. J. Eng. Educ.*, **32**(3), 2016, pp. 1438–1444.
15. D. Dougherty, The maker mindset, *Des. Make Play Grow. Gener. STEM Innov.*, 2013, pp. 7–11.
16. M. Z. Donahue, What Is a Maker Faire, Exactly?, *Smithsonian*, 12-Jun-2015. [Online]. Available: http://www. smithsonianmag.com/innovation/what-maker-faire-exactly-180955574/ [accessed: 20-Apr-2017].
17. D. Lang, *Zero to Maker: Learn (Just Enough) to Make (Just About) Anything*. Maker Media, Inc., 2013.
18. S. Kuznetsov and E. Paulos, Rise of the expert amateur: DIY projects, communities, and cultures, in *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, 2010, pp. 295–304.
19. K. Sheridan, E. R. Halverson, B. Litts, L. Brahms, L. Jacobs-Priebe and T. Owens, Learning in the making: A comparative case study of three makerspaces, *Harv. Educ. Rev.*, **84**(4), 2014, pp. 505–531.
20. S. Jordan and M. Lande, Additive innovation in design thinking and Making, in *Proceedings of the Mudd Design Workshop IX: Design Thinking in Design Education*, Harvey Mudd College, Claremont, CA, 2015, pp. 132–140.
21. B. Herold, The 'Maker' Movement Is Coming to K-12: Can Schools Get It Right?, *Education Week*, 09-Jun-2016.
22. National Academy of Sciences (U.S.) Staff and National Academy of Engineering (U.S.) Staff, *Rising above the Gathering Storm, Revisited: Rapidly Approaching Category 5*, Washington, US: National Academies Press, 2010.
23. National Commission on Excellence in Education, *A Nation at Risk: The Imperative for Educational Reform*, Washington, D.C., 1983.
24. Reform in K-12 STEM education: hearing before the Committee on Science and Technology, House of Representatives, One Hundred Eleventh Congress, second session, March 4, 2010, *Reform K-12 STEM Educ. Hear. Comm.*

Sci. Technol. House Represent. One Hundred Elev. Congr. Second Sess. March 4, 2010, p. i-60, Mar. 2010.
25. L. Martin, The Promise of the Maker Movement for Education, *J. Pre-Coll. Eng. Educ. Res. J-PEER*, **5**(1), Apr. 2015.
26. J. Bean and D. Rosner, Making: movement or brand?, *interactions*, **21**(1), 2014, pp. 26–27.
27. S. C. Sivek, 'We Need a Showing of All Hands': Technological Utopianism in MAKE Magazine, *J. Commun. Inq.*, **35**(3), 2011, pp. 187–209.
28. About Maker Ed, *Maker Education Initiative*. [Online]. Available: http://makered.org/about-us/who-we-are/ [accessed: 01-Feb-2017].
29. S. Papert, *Mindstorms: children, computers, and powerful ideas*, New York: Basic Books, 1980.
30. L. Brahms, Making as a learning process: Identifying and supporting family learning in informal settings, University of Pittsburgh, 2014.
31. C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey and L. J. Leifer, Engineering Design Thinking, Teaching, and Learning, *J. Eng. Educ.*, **94**(1), 2005, pp. 103–120.
32. *Maker-centered Learning and the Development of the Self: Preliminary Findings of the Agency By Design Project*, Harvard Graduate School of Education, Jan. 2015.
33. M. Lande, S. Jordan and S. Weiner, Making people and projects: Implications for making-based learning, presented at the *ASEE Pacific Southwest Conference*, Tempe, AZ, 2017.
34. D. Dougherty, Cleveland's Thinkbox Is a Big Bet on University Makerspaces | Make, *Make: DIY Projects and Ideas for Makers*, 30-Oct-2015. [Online]. Available: http://makezine. com/2015/10/30/clevelands-thinkbox-is-a-big-bet-on-university-makerspaces/ [accessed: 23-Apr-2017].
35. Free, Mobile Maker Lab With STEM Programs Coming Through The Region, *Campbell, CA Patch*, 12-Dec-2016. [Online]. Available: https://patch.com/california/campbell/free-mobile-maker-lab-stem-programs-coming-through-region [accessed: 23-Apr-2017].
36. S. Doorley, S. Witthoft, H. P. I. of D. at S. University and D. Kelley, *Make Space: How to Set the Stage for Creative Collaboration*, 1 edition. Hoboken, N.J: Wiley, 2012.
37. V. Kostakis, V. Niaros and C. Giotitsas, Production and governance in hackerspaces: A manifestation of Commons-based peer production in the physical realm?, *Int. J. Cult. Stud.*, **18**(5), 2015, pp. 555–573.
38. H. Flum and A. Kaplan, Identity formation in educational settings: A contextualized view of theory and research in practice, *Contemp. Educ. Psychol.*, **37**(3), 2012, pp. 240–245.
39. K. C. McLean and M. W. Pratt, Life's little (and big) lessons: Identity statuses and meaning-making in the turning point narratives of emerging adults, *Dev. Psychol.*, **42**(4), 2006, pp. 714–722.
40. K. L. Tonso, Teams that Work: Campus Culture, Engineer Identity, and Social Interactions, *J. Eng. Educ.*, **95**(1), 2006, pp. 25–37.
41. L. D. McNair, C. Newswander, D. Boden and M. Borrego, Student and faculty interdisciplinary identities in self-managed teams, *J. Eng. Educ.*, **100**(2), 2011, p. 374.
42. B. M. Capobianco, B. F. French and H. A. Diefes-Dux, Engineering Identity Development Among Pre-Adolescent Learners, *J. Eng. Educ.*, **101**(4), 2012, p. 698.
43. K. Tobin, C. Ali-Khan and M. Varelas, *Identity Construction and Science Education Research: Learning, Teaching, and Being in Multiple Contexts*, Rotterdam, NL: Sense Publishers, 2012.
44. W. Faulkner, 'Nuts and Bolts and People': Gender-Troubled Engineering Identities, *Soc. Stud. Sci.*, **37**(3), 2007, pp. 331–356.
45. L. Strong, The intersection of identity, culture and science engagement, *Cult. Stud. Sci. Educ.*, **11**(2), 2016, p. 379.
46. S. Weiner, M. Lande and S. Jordan, Making Identities: Understanding the factors that lead young adults to identify with the Maker Movement, in *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Columbus, OH, 2017.
47. J. P. Gee, Identity as an Analytic Lens for Research in Education, *Rev. Res. Educ.*, **25**, 2000, pp. 99–125.
48. J. Corbin and A. Strauss, *Basics of qualitative research: Techniques and procedures for developing grounded theory*, Sage publications, 2014.
49. J. C. Flanagan, The critical incident technique, *Psychol. Bull.*, **51**(4), 1954, p. 327.
50. M. Q. Patton, *Qualitative research and evaluation methods*, Thousand Oaks, CA: Sage Publications, 2002.
51. J. W. Creswell, *30 Essential Skills for the Qualitative Researcher*. Thousand Oaks, California: SAGE Publications, Inc, 2015.
52. Alice Pawley, 'Learning from small numbers' of underrepresented students' stories: Discussing a method to learn about institutional structure through narrative, presented at the *American Society for Engineering Education Annual Conference and Exposition*, 2013.
53. L. M. Given, Negative Case Analysis, *The SAGE Encyclopedia of Qualitative Research Methods*. Sage Publications, 2008.
54. J. E. Marcia, Development and Validation of Ego-Identity Status, *J. Personal. Soc. Psychol. Wash. DC*, **3**(5), 1966, p. 551.
55. A. Hochanadel and D. Finamore, Fixed and growth mindset in education and how grit helps students persist in the face of adversity, *J. Int. Educ. Res.*, **11**(1), 2015, p. 47.
56. B. Barron, Interest and Self-Sustained Learning as Catalysts of Development: A Learning Ecology Perspective, *Hum. Dev.*, **49**(4), 2006, pp. 193–224.
57. P. C. Blumenfeld, E. Soloway, R. W. Marx, J. S. Krajcik, M. Guzdial and A. Palincsar, Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning, *Educ. Psychol.*, **26**(3/4), 1991, p. 369.

Steven Weiner is a PhD student in Human and Social Dimensions of Science and Technology at the School for the Future of Innovation in Society at Arizona State University. He is interested in researching innovative learning frameworks at the intersection of formal and informal STEM education, specifically focusing on how the Maker movement can help shape institutional culture and learner identity. Before starting his doctoral studies, Mr. Weiner served as the founding Program Director for CREATE at Arizona Science Center, a hybrid educational makerspace/community learning center. He has previous experience as a physics and math instructor at the middle school and high school levels.

Micah Lande, PhD is an Assistant Professor in the Engineering and Manufacturing Engineering programs and Tooker Professor at the Polytechnic School in the Ira A. Fulton Schools of Engineering at Arizona State University. He teaches human-centered engineering design, design thinking, and design innovation project courses. Dr. Lande researches how technical and non-technical people learn and apply a design process to their work. He is interested in the intersection of designerly epistemic identities and vocational pathways. Dr. Lande is the PI/co-PI on NSF-funded projects focused on engineering doing and making, citizen science and engineering outreach, and "revolutionizing" engineering education. He has also been an instructor and participant in the NSF Innovation Corps for Learning program. He received his BS in Engineering (Product Design), MA in Education (Learning, Design and Technology) and PhD in Mechanical Engineering (Design Education) from Stanford University.

Shawn Jordan, PhD is an Associate 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 PhD in Engineering Education (2010) and MS/BS 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?," and is a Co-PI on the NSF Revolutionizing Engineering Departments grant "Additive Innovation: An Educational Ecosystem of Making and Risk Taking." He was named one of ASEE PRISM's "20 Faculty Under 40" in 2014 and received a Presidential Early Career Award for Scientists and Engineers from President Obama in 2017.

Appendix

Description of Categories from the Modified Version of Gee's Framework [46]

Nature-identity	Describes the identity lens that is most distant from the individual's actions or control. N-identity is classified as being something inherent or innate in an individual, generally that they were born with, or born into. This can be physical attributes, like being tall or having twins or circumstances in which they were put, like having a mother who was a Maker. This is not to be confused with Institutional-identity, which specifically indicates characteristics ascribed from an institutional position or relationship.
Social Discourse-identity	Typified by identity characteristics that are generated through interactions with other individuals. The notions that people can be "funny", "charismatic", "introverted", or "intelligent" stems from discursive interactions and thus do not emerge independent of these social contexts. D-identity is not fully achieved or ascribed but a mixture of the two, as people navigate social situations and respond by emphasizing or omitting certain ways of communicating.
Material Discourse-identity	This identity was derived from comments made by young Makers in which they ascribed personal qualities to themselves, like "patient" and "persistent" based on their experiences in working with different media and equipment. These interactions seemed to constitute a material, as opposed to social, discourse.
Affinity-identity	The identity that emerges when an individual engages in certain behaviors and activities that align themselves with an affinity group. An affinity group is a collection of individuals who have shared interests. While the Affinity-identity is still tied to the affinity group in which the individual considers him or herself, it is –in some sense–the most fully achieved identity, since an individual must intentionally act to be a part of the group. The Maker Movement is example of an affinity group (or perhaps an affiliation of related affinity groups), but it is important to recognize when individuals engage with the Maker community in ways that are not related to affinity.
Institutional-identity	This category asserts that institutions can bestow elements of identity on an individual simply due to their position within or relationship to an institution. Such identities range from "teacher" or "student" to "patient" and "doctor" or even "consumer" or "constituent". The Institutional-identity is mostly not considered achieved or earned but socially ascribed.
Preferential-identity	Preferential identities are built on what young Makers say that "they like". Unlike Affinity-identities, preferential identities don't seem to be based on interactions or practices with others, but instead are fundamentally individual and potentially seen as an innate or "natural" characteristics. Preferential identities are also related to Affinity-identities in that interests or preferences drive them. Thus, this is a sub-category of both Nature and Affinity identities.
Relational-identity	This category classifies all activities that are primarily based on a relationship with someone else, such as "friend", "brother", or "daughter". These relations are different than institutional relationships, since they foreground the specific person, as opposed to a role within an organization.