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ENTREPRENEURSHIP RESEARCH, MAKERS, AND THE MAKER MOVEMENT

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ABSTRACT

The maker movement differs from other forms of entrepreneurship in its use of engineering heuristics and focus on collaborative interactions around specific technological tools and practices fostering innovative outcomes. As a practice and a field for scholarly investigation, it provides new opportunities for broadening theoretical assumptions concerning entrepreneurship, management, and organizational research. For example, we argue that the maker movement generates unique forms of innovation and entrepreneurship in areas that have historically been dominated by larger and better-endowed organizations. We frame our contribution through Herbert Simon's perspectives on the science of the artificial and the philosophy of technology, focusing on makers as designers who are intent upon improving – they might say "hacking" – what they encounter in the natural world. Makers do not accept the environment as they find it, but instead artificially reshape it to their own designs.

INTRODUCTION

The maker movement is an umbrella term commonly used to capture a variety of formal and informal activities, firms and actors, including do-it-yourself (DIY) hobbyists, artists, students and educators, self-employed small business owners, prototyping entrepreneurs, technology inventors and disruptors, corporate innovators, and a new breed of manufacturers. As a movement, it has benefitted from technologically driven transformations that have facilitated small-scale but high-quality production and have thus steadily eroded barriers to production, increasing the potential for innovation and entrepreneurship. Growing recognition of its importance has also sparked increasing interest from the mass media (Anderson, 2012; Hatch, 2014). The movement has myriad implications for scholars interested in technological change, national industrial and economic policy, revitalizing of industrial manufacturing, urban planning, and the redesign of primary education. We believe the maker movement is ripe for exploration by entrepreneurship scholars and lay out our argument in this paper.

Since the landmark insights of Joseph Schumpeter (1934), management scholars have viewed entrepreneurs and firms as producers of innovations. Baldwin and von Hippel (2011) pointed out that firms rather than individuals have historically been seen as the sources of innovation as well as owners of property rights in innovations they generate. As a result of developments in the sharing economy and open collaboration innovation, a significant paradigm shift has disrupted the traditional view of production. Single-users, such as firms and individuals, can now profit by disintermediating traditional modes of production and supply chains through innovative activities (Baldwin & von Hippel, 2011). Moreover, users are not only more likely to be a key source of innovations but also to treat innovations that improve user experiences as valued in and of themselves, regardless of whether they also earn a profit.

Exogenous shocks through such technological advances are thus changing market dynamics (Schumpeter, 1942). Transformative changes are shifting the locus of power downstream toward users, pressuring firms to redesign value chains “from the customer backward (demand pull) instead of from the factory outward (supply push)” (Christopher & Ryals, 2014: 29). Acs and Audretsch (1990: 110–126) detected this development in the 1980s, observing an increase in the number of small businesses in engineering industries affected by the adoption of CNC (computer numerical control) and flexible manufacturing, including programmable robots. From a strategy perspective, the new developments are removing barriers along the value chain by lowering costs and increasing access for design, prototyping, manufacturing, selling and distribution (Hagel, Brown, & Kulasooriya, 2013). For engineers, the shift from “slide rule to computer” (Petroski, 1985: Chapter 15) has been profound, with engineering as a profession heavily affected by developments such as the invention of 3D printing, or additive manufacturing, during this same period (Ford, Mortara, & Minshall, 2016; Hull, 2015).

Recognizing these contextual changes, some scholars are questioning the Schumpeterian framework of R&D and production as the purview of large corporations (Weiser, 2003), characterizing these changes as “an explicit challenge to industrial-era hierarchical enterprise” and “the emergence of a new era of collaborative entrepreneurship” (Stacey, 2014: 228–229). The maker movement has grown rapidly amid this widening technological access and open collaboration, with some observers predicting that it will increase entrepreneurship worldwide. However, not everyone agrees on the future of the movement, with some maker participants and observers noting serious obstacles confronting those who wish to harness its entrepreneurial potential (Troxler & Dunajcsik, 2014). Nonetheless, recent developments strongly suggest that the maker movement has a powerful potential as a mechanism for innovation and entrepreneurial action on a societal scale.

Despite this potential and the fact that the maker movement is now in its second decade and building momentum, the literature connecting makers and entrepreneurship is limited with a few recent exceptions (Aldrich, 2014; Mortara & Parisot, 2016). Similarly, the strategy and management literature has included only a handful of mentions of the general topic within broader discussions (Davis, 2016; Dhebar, 2016; Furnari, 2014; Kohler, 2015; Kortmann & Piller, 2016) with little significant empirical work to date. This article aims to describe common patterns and features of the maker movement in order to guide future research. Our premise is that if the maker movement is to become a recognized area for research in entrepreneurship and innovation, further identification and clarification of key concepts, constructs and theories are needed. We believe that in exploring the maker movement as a field of research, entrepreneurship and management scholars can address important theoretical and empirical gaps informing policy and practice.

While the approach to the maker movement put forth in this paper is tentative, we believe it offers two key contributions. First, we provide a rationale for viewing the maker movement as an area ripe for entrepreneurship research, both in terms of its novelty and in the accessibility it provides for scholars to study the changing contextual dynamics of innovation and entrepreneurship. Second, we build upon and extend the literature on the science of the artificial (Sarasvathy, 2003; Simon, 1996; Venkataraman, Sarasvathy, Dew, & Forster, 2012) and associated work from philosophy of technology as theoretical foundations for studying makers as an entrepreneurial form. We believe the creative activity in the maker movement requires frameworks that account for contributions from the fields of engineering/design and entrepreneurship. In the following sections, we begin by introducing the maker movement and its relationship to entrepreneurship at the individual and macro levels. Next, we present potentially useful theoretical frameworks considering entrepreneurship as a science of the artificial (Sarasvathy, 2003; Simon, 1996; Venkataraman et al., 2012) and establishing links to the field of engineering and the philosophy of technology necessary to understand who makers are and what they do. We finish by offering possible avenues for future research.

WHAT IS THE MAKER MOVEMENT?

Following Anderson (2012) and others, we define the maker movement as consisting of people utilizing technology to collaborate in creating tangible, material artifacts. By artifacts, we refer to the original Latin meaning of "something made with skill." Artifacts reflect both "an 'inner' environment, the substance and organization of the artifact itself, and an 'outer' environment, the surroundings in which it operates" (Simon, 1996: 6). The designer's purpose lies at this interface, matching the inner environment to the outer environment. For example, a car engine's inner environment is its fuel supply, pistons, etc. and its external environment is the vehicle it powers, along with roads and associated infrastructure. Often makers not only produce artifacts but also purpose to distribute them commercially. Makers act in local and global markets as producers, not just consumers, by leveraging shared access to knowledge and tools applying technology in their own projects (Dougherty, 2016).

Makers require no formal training or certification. Instead, they need only the opportunity and willingness to access the resources of the movement, including fabrication tools like 3D printers, design files, skills training, and the network of other makers. The broadening availability of new and often expensive technologies in maker spaces expands R&D beyond highly resourced corporations, democratizing invention and innovation (Blikstein, 2014; von Hippel, 2005: 121). Many insiders describe the movement itself, or specific technologies associated with it such as 3D printing, as the next industrial revolution (Anderson, 2012; Maietta & Aliverti, 2015). With significant increases in access to the means of production, knowledge of how to produce, and reductions in barriers to entry, some assert that the potential exists for a revolution in manufacturing, industrial R&D, consumer goods, retail and the nature of collaborative work for a global talent pool (Hagel et al., 2013).

Terms sometimes utilized other than "maker movement/culture" include "DIY" movement/culture and "hacker" movement/culture (Dougherty, 2016: 9; Hatch, 2014; Maietta & Aliverti, 2015: 7)[1]. Makers work with open source hardware, which refers to "shared information related to physical artifacts" (Aitamurto, Holland, & Hussain, 2015: 19), including the machinery of production and the material output itself. Other broad terms associated with the maker movement include peer production (Troxler & Dunajcsik, 2014) and the democratization of research and development (R&D), which refers to the miniaturization, digitization and economization of the tools of production.

Examples of the maker movement in action include individuals whose curiosity to design or create leads to entrepreneurial endeavors (Lang, 2013), corporate sponsored employee innovation projects (e.g. Ford), platforms for sourcing designs from others (e.g. Quirky) or the production of one's own designs (e.g. Ponoko), and a growing network of local, national and international shared fabrication facilities (e.g. Fab Labs, TechShop). The shared technologies range from basic woodworking tools to injection molding and biotechnology equipment (Kera, 2014; Schmieder & Andrew-Wani, 2014). The increased availability and affordability of

[1] We have avoided using the term "hacker" due to its origins in the open source software movement and its potential to obscure our focus on hardware (Dougherty, 2016: 14).

electronic sensors enables makers of all types to embed the hardware they produce in the Internet of Things (IoT). The capability of "a digital thread from the raw materials all the way through to the finished product" (Merfeld, 2014: 28) has opened the possibility for any individual or firm in the world to go from design to production or collaborate with others to produce a finished product.

INSERT FIGURE 1 ABOUT HERE

Drawing from the literature and our observations, we illustrate three key components of the maker movement in Figure 1: technology, spaces, and community. First, *technology* refers to the tools of production used by makers. Makers can use a broad combination of tools that include traditional woodworking and metalworking tools together with newer technologies like 3D printers, laser cutters, CNC milling machines, microcontroller kits and programming tools (Anderson, 2012; Maietta & Aliverti, 2015). Gershenfeld (2015: 18), founder of the MIT Center for Bits and Atoms program, points to the parallel between the digitization of communication and computation and the subsequent digitization of fabrication: "It is about the boundary between the digital and physical worlds at the edges—how data objects become data in the network and data in the network become objects." The digitization enabled by technology relates not only to the products and methods of production, but also to locations where production can occur. This can be seen in companies that are localizing production in close proximity to intended consumers (Bianchini & Maffei, 2012; Christopher & Ryals, 2014). Further, it changes who the producer can be, with consumers themselves now included as user-producers (Baldwin & von Hippel, 2011; Kohler, 2015).

Second, user/producers constitute the *community* of people who make use of the technology. Other terms that are sometimes used interchangeably with maker include "hacker," "crafter" and "fabber" (Roedl, Bardzell, & Bardzell, 2015). For many makers, especially at the hobbyist level, self-made products are an extension of self and a form of creative self-expression (Atakan, Bagozzi, & Yoon, 2014). For others who make to invent, prototype, or manufacture in small-batches, it is about creating solutions to meet tangible needs and solve problems. Either way, the essence of making taps into an individual's identity because "the ideas of engineering are in fact in our bones and part of our human nature and experience" (Petroski, 1985: ix). While archeological findings of ancient tools remind us that individuals have made things throughout all of human history (Koen, 2003: 9), proponents of the maker movement claim a distinct advancement due to the collaborative connections people cultivate with a broader maker community network facilitated by technology and globalization (Cohen & Muñoz, 2016; Williams, Lindtner, Anderson, & Dourish, 2014). Similarly, we view this ability to get ideas and make things in community – both of which are enabled and accelerated by technology – as markedly different from the makers of the past who were confined to either their corporate laboratory or their garage at home. We also see this emerging organizational form as distinctive from other "sharing economy" organizational forms. Rather than sharing a conventional resource in a didactic relationship (e.g. car sharing), potential combinations of tools and a wider collaborative network may lead to a potential range of innovative outcomes.

Third, the *spaces* where the community of makers gains access to use new technologies constitute the third component of our framework. As shown in Figure 1, the material nature of the tools used by makers as they craft physical products means that the community and the technology must intersect in shared spaces. These physical and digital access points connect makers to others in the global network and their ideas and expertise through the Internet, Maker Faire conferences (Dougherty, 2016: xvii) and through local "maker spaces" that provide communal access to tools and resources (Williams et al., 2014). Maker spaces are shared fabrication places that "modify the conception of the traditional sites of production and recast the notions of studio, workshop, laboratory, gallery, and atelier into new settings for the integrated design, production, and distribution of products" (Bianchini & Maffei, 2012: 6). Other terms that are sometimes used instead of maker space include "hackerspace," "shared machine shop," and the branded Fab Lab or TechShop. In addition to access to the maker community and maker spaces, the elimination of traditional barriers of entry provides access to the tools of production and combines them with increased access to channels of distribution through online marketplaces (Kohler, 2015).

The Maker Movement and Entrepreneurship

While not all makers have entrepreneurial intent, the three key components shown in Figure 1 are associated with the physical, social and knowledge capital that may be needed if a design is pursued as an entrepreneurial opportunity in the market. A walk through a typical maker space or Maker Faire provides an introduction to a range of makers in terms of entrepreneurial intent, stage of development and scale. In our field observations and as described in the academic and general literature, we observe a spectrum of entrepreneurial activity among makers, which we summarize in Figure 2 according to the scale and scope of the entrepreneurial intent and action involved in the projects they pursue.

INSERT FIGURE 2 ABOUT HERE

Moving from left to right in Figure 2, *hobbyists* are tinkerers and crafters with limited scale and scope whose making is an end in itself. Some of these makers discover that others are interested in purchasing their products and subsequently decide to supplement their income with occasional projects for individual customers or offer their expertise to other makers. Whether a business opportunity is discovered in this way or a maker deliberately sets out to start a small business, the next group can be described as *lifestyle entrepreneurs*. These makers exhibit more entrepreneurial actions and express greater entrepreneurial intent than hobbyists. Many of the products made by lifestyle entrepreneurs are consumer focused, often appearing as projects on crowdfunding sites like Kickstarter. Channels of distribution such as Etsy.com have opened up larger markets for the niche products that these makers create. The Grommet is an example of a platform for helping makers bring their products to market as a launch service as well as a sales channel (Pieri & Domeniconi, 2016).

Growth entrepreneurs often enter maker spaces with an innovative product and a business underway. These entrepreneurs engage in rapid prototyping for product development as well as small-batch manufacturing. The shared facilities and tools help them overcome resource constraints that would have been a limitation previously. One example is the Nifty Minidrive, which provides additional storage to laptop computers. It was invented and manufactured in a maker space in Manchester, UK, and funded through Kickstarter (Stacey, 2014). Square is another growth example in the business-to-business category. Co-founder Jim McKelvey prototyped the Square credit card reader for mobile phones at a maker space in Silicon Valley so that his company could test its business model and secure venture capital backing (Anderson, 2012: 199). Without a working prototype, potential investors were unsure of the concept and the founders debated if the company even needed a hardware component to read credit cards.

Of larger scale and scope in Figure 2, *corporate innovators* leverage the resources of the maker movement – such as maker spaces and geographically distributed design and creative talent – for R&D and product development or for experimenting with materials and process improvements that reduce current production costs. While corporations often have their own R&D labs, the fragmented nature of corporate functions often limit the range of tools and collaboration that a corporate engineer or designer can access during a work day. To stimulate creativity, some corporations buy maker space memberships and offer them as incentives for employees to problem solve and innovate where they have greater flexibility, more tools and new collaborative partners to share ideas with. Corporate leaders are taking note that the nature of work is shifting for many of their employees and that even a well-outfitted corporate laboratory may not supply all the material, social and mental resources needed to stimulate invention and creative problem solving. One such example is TechShop's Detroit location, which was established in partnership with the Ford Motor Company in order to accelerate employee patent rates.

While our model simplifies the diversity and range of entrepreneurial intent and action observed along the spectrum of maker entrepreneurship, these categories and examples provide a helpful starting point for future research at multiple levels of analysis. We expect increasing investment in innovations along this spectrum in the coming years, given the interest the maker movement has garnered from public policy makers.

Entrepreneurship, the Maker Movement, and Public Policy

Recent actions at the macro scale indicate that international policy makers believe that bolstering population-level capability development with initiatives that encourage making will lead to increasing innovation and improved economic growth. Indeed, the same technologies used by individual makers to experiment and complete small-scale projects also have implications at a larger scale. Additive technology, for example, is also fueling discussions about building 3D printing infrastructures that increase efficiency and reverse the outsourcing of manufacturing (Birtchnell, Böhme, & Gorkin, 2016; Blinder, 2006). Governments are "jostling to lead in technology development in everything from manufacturing competitive advantage to advanced defence superiority" (Birtchnell et al., 2016: 5). The convergence of production and national defense agendas reminds us that the maker phenomenon has its technical roots in the CNC technology developed in the last century. Cardosa Llach (2015: 48) made this connection in commenting on The Defense Advanced Research Projects Agency (DARPA) slogans: 'to innovate we must make, to protect we must produce' and 'Democratize Design,' noting that they "illustrate the collapse, in public military discourse, of design and manufacturing technologies with national security imperatives." DARPA continues to be an active partner and investor in civil programs, including the maker movement (Britton, 2015; Dougherty, 2016; Hatch, 2014).

In the *United States*, DARPA and other funding agencies such as the National Science Foundation (NSF) and the Institute for Museum and Library Services (IMLS) provide grant funding to initiatives within the maker movement with an emphasis on STEM (science, technology, engineering and mathematics) education (Britton, 2015; IMLS, 2015; NSF, 2015). In 2014, President Obama announced an initiative for the United States to be 'A Nation of Makers,' planning "to support opportunities for students to learn about STEM through making, expand the resources available for maker entrepreneurs, and foster the development of advanced manufacturing in the U.S." (White House, 2016: para. 2). 'America Makes' is the brand name of the National Additive Manufacturing Innovation Institute (NAMII) and part of the National Center for Defense Manufacturing and Machining (NCDMM). This initiative is an example of public interests being pursued in concert with public and private resources from a wide combination of disciplines, geographies and organizations (Klein, Mahoney, McGahan, & Pitelis, 2010; Ostrom, 1990). It aims to "develop the standards, tools, education, and research required to accelerate the U.S. manufacturing industry into a dominant, global economic force" (NCDMM, 2016: para. 1).

In *Europe*, the European Commission promotes the maker movement, claiming to have the most maker spaces of any continent and that the movement is "spreading the culture of Digital Manufacturing and Industry 4.0, which are the keys to make the European economy flourish again" (EU Policy Lab, 2016: para. 5). The emphases in Europe are similar to those in the United States – spurring economic growth, manufacturing and education – with the added dynamics of the opportunities and uncertainties afforded by a single European Union (EU) market (Bachtler & Mendez, 2016; Howard, Gerosa, Mejuto, & Giannella, 2014). This is evidenced in the EU-funded DIGINOVA project, a consortium of 20 European countries, universities and institutions aimed at advancing and aligning a digital fabrication industry (Potstada, Parandian, Robinson, & Zybura, 2016).

China announced a new national policy on "mass makerspaces" weeks after Prime Minister Li Keqiang visited a maker space in Shenzhen, China's manufacturing epicenter, in January 2015. The policy aims to cultivate "self-making" and "self-entrepreneurship" to democratize and speed up innovation, technology and scientific advancements, and contribute to economic growth through entrepreneurs, financing and innovation hubs (Lindtner, 2015). Lindtner's (2014, 2015; Williams et al., 2014) ethnographic research in the fields of informatics and design has documented these developments and the distinctive character of the maker movement in China: "The goal of this political agenda has been to turn China into a leading information and knowledge economy that surpasses its reliance on 'made in China' by developing new industries that produce innovation 'created in China'" (Lindtner, 2015: 861). The Chinese government now endorses making as part of a larger politico-economic strategy, with entrepreneurs subsidized to set up commercial maker spaces for other entrepreneurs (Lindtner, 2015).

Emerging economies have also taken an interest in maker spaces. Entrepreneurship rates in these nations exceed those of more developed economies (Levie, Autio, Acs, & Hart, 2014) due to the prevalence of necessity-based entrepreneurs (Reynolds, Camp, Bygrave, Auito, & Hay, 2001). The democratization of creative production and reduced barriers to entry have caught the attention of social entrepreneurs (Linna, 2013) and policy makers focused on workforce education and human capacity development (Ponelis & Holmner, 2015). Similar dynamics driving the maker movement might allow marginalized populations participation opportunities in the global economy, not only as consumers at the bottom of the pyramid (BOP), but as producers as well (Prahalad, 2012). Subsistence economy contexts have their own challenges, concerning unequal access to the resources of the maker movement. However, opportunities for greater access are growing as technology entrepreneurs in these markets pioneer their own hardware-based solutions to the needs and challenges of their societies (Koh, Hegde, & Das, 2016; Linna, 2013; Pan, 2014).

The evidence provided here of maker activity from diverse examples suggest its importance as a context for entrepreneurship and innovation. However, the following question remains: Are there distinctive features of the maker movement that expand our general theoretical and empirical understanding of entrepreneurship? We believe that the unique set of technology tools, the spaces where these tools are used, and the collaborative sharing of technical knowledge and production shift the boundaries and required theorizing of how products are generated. The technologies makers require access to are carefully thought out – often with significant investment by maker spaces – generating entrepreneurship that is likely different from bootstrapping (Starr & MacMillan, 1990) or resource constrained bricoleurs (Baker & Nelson, 2005).

Although bricolage also contains themes of resource sharing and collaboration in the construction of technology (c.f. Garud & Karnøe, 2003), engineering and design in maker entrepreneurship differ in significant ways from entrepreneurship models in sociology, psychology or economics alone. In the following section, we offer alternative theory that takes note of the tools and purposeful actions of creators in matching the internal features of their artifact design to the external environment. These theories also incorporate, to some degree, organization in the design process and the social nature of technology construction, but may be brought together with current insights from sociology, organizations and other theories in use to enrich our theoretical understanding of makers in entrepreneurship.

THEORETICAL FRAMEWORKS FOR ENTREPRENEURSHIP RESEARCH ON THE MAKER MOVEMENT

In the three components, shown in Figure 1, the underlying link generating action stems from makers and others in the community gaining access to technologies in various kinds of maker spaces, where they bring into being material artifacts they have designed themselves or whose designs they have borrowed from others. Often the designs emerge as makers experiment with the resources at hand, learning how to use the tools available to them and taking advice from others in the community of makers. In this respect, makers are carrying on a tradition of craftwork that is centuries old, predating the formalization of criteria for calling oneself an "engineer." Faced with the problem of actualizing their designs, makers share tools, expertise and ideas in a very practical way. They do not accept the environment as they found it, but rather artificially reshape it to their own designs.

We review several relatively underutilized theoretical frameworks for understanding entrepreneurship in the maker context. Our account of the situation facing makers fits well with Herbert Simon's "The Sciences of the Artificial" (1996), in which he described the key persona of the engineer, the process of design, and the production of artifacts. Simon (1996: 53) argued that explanations for human action should be sought by examining complexity in environments more so than in human behavior. Simon's student, Saras Sarasvathy built on his work to argue that entrepreneurship is a science of the artificial (2003) and described entrepreneurial action in uncertain environments as "effectuation" (2001). Venkataraman et al. (2012) pointed to the science of the artificial as a framework for exploring the action-interaction nexus (Dimov, 2011), in contrast to models focusing on the individual-opportunity nexus.

Reconnecting entrepreneurship theory to an emphasis on the sciences of the artificial provides a theoretical connection with the broader philosophy of technology and engineering literatures which consider decision making, purpose and action in the production of artifacts. In making these connections, we offer common ground for a theoretical perspective on maker entrepreneurs. We also highlight the central figure of the engineer and the central activity of design. For entrepreneurship in the making, these concepts are important for both organizational and product design. Whereas our framework in Figures 1 and 2 spoke to the overall system of the maker movement, we focus now specifically on what makers are actually doing as they go about their making and what happens when they attempt to commercialize what they have created.

The Sciences of the Artificial & the Centrality of Design

Simon distinguished between the natural world and the artificial world, saying that artificial systems change because they are contingent on the environment (1996: xi). He placed engineering and business squarely in this category: “Engineering, medicine, business, architecture, and painting are concerned not with the necessary but with the contingent – not with how things are but with how they might be – in short with design” (Simon, 1996: xii). The engineer and the business person – we might substitute “the maker and the entrepreneur” – are concerned with designing and making artifacts for the purpose of managing and improving their complex, uncertain and changing environments.

The science of the artificial can be equated with the science of design and is a close kin to the science of engineering (Simon, 1996: 5, 111). Engineers do more than practice technology as applied science (Petroski, 2010: 45; Vries, 2003); rather, they design with purposeful goals: “The engineer is concerned with how things ought to be – ought to be, that is, in order to attain goals, and to function” (Simon, 1996: 4). Arguing that design is social in action and in purpose, Simon placed social interactions and human purposes at the center of the design process (Simon, 1996: 154). An entrepreneurial opportunity, a firm, or even a market can be an artifact (Sarasvathy, 2003; Venkataraman et al., 2012). Regarding the materiality of products as artifacts, Petroski distinguished engineering from the natural sciences because “engineers hypothesize about assemblages of concrete and steel that they arrange into a world of their own making" (1985: 43). Particularly in the hands-on, physical/digital world of the maker, artifacts “are not invisible, nor weightless,” but “socially and materially constituted” (Cardoso Llach, 2015). In fact, in today’s market environment, “the relationship between design and artifact production is more complicated because everyday human experience is being populated by interactive and complex objects of a material/nonmaterial nature and in continuous and rapid evolution (mix of hardware and software via connection with services)" (Bianchini & Maffei, 2012).

INSERT FIGURE 3 ABOUT HERE

Design is the key concept for entrepreneurship in the making (Williams et al., 2014). As makers apply the engineering method formally or informally to create product and business artifacts, they operate in the *design plane*, as shown in Figure 3. The figure was generated by cross classifying two dimensions: the horizontal axis explains what is being designed – the nature of the artifact being commercialized (product or business), and the vertical axis explains who is designing – the extent to which specialized knowledge is widely available. The lower row depends on knowledge that is widely distributed across makers, regardless of depth of engineering training, whereas the upper row reflects knowledge available mainly to professionals. Cross classification of these two dimensions produces the four cells we discuss below.

In Cell A, n*ew product development* is the traditional domain of professional engineers who focus on creating new products to meet design and production specifications. Often, those specifications come from and are funded by an existing *corporate venturing* initiative through a formal R&D or new product commercialization program, as shown in Cell B. Cell C in the design plane is for *individual makers innovating*. These makers typically must achieve commercial viability by finding a profitable way to produce and distribute their artifacts before deciding whether to continue as an independent firm or be acquired by another corporation. Cell

D reflects contexts in which a professional engineer or amateur maker can work as part of a start-up team to attempt to bring a product to market as part of *creating new ventures*.

While engineering design is technical in nature, the essence of design is actually *problem solving* and decision making, a process that pervades all four cells in Figure 3. For Simon, problem solving, and therefore design, is truly about strategy (1996: 62) regarding means and ends. When dealing with the artificial, the design process is the "adaptation of means to environments" (Simon, 1996: 113). It is a process of optimization. Regarding ends in artificial systems, it is more important to create solutions that work in context than it is to uncover universal truths. It is about finding the optimum solution that achieves the intended purpose or function in that environment. For this, Simon introduces the concept of satisficing (1996: 119), which involves iterating and using heuristics to come up with the most satisfactory design while managing the limited resources of the designer. Not unlike bricolage (Baker & Nelson, 2005), resourcefulness (Bradley, Aldrich, Shepherd, & Wiklund, 2011) or entrepreneurial search (Bradley, Patel, McMullen, & Parida, 2011), "problem-solving systems and design procedures in the real world do not merely assemble problem solutions from components but must search for appropriate assemblies" (Simon, 1996: 124). Cells A and C in Figure 3 present problem solving in the design and creation of new products, whereas Cells B and D present problem solving in the service of commercializing products, either for new ventures or within established firms.

A view of entrepreneurship as a science of the artificial places it in the same camp as engineering, technology, and design. These perspectives share much common theoretical grounding and can prove to be compelling conversation partners. Having this conversation in the context of the maker movement, grounded in the materiality of producing tangible goods, provides fertile ground for theoretical exploration. We turn now to examining the process of maker-entrepreneurs in action: engineering methods and the philosophy of technology.

The Engineering Method

On visits to maker spaces or Maker Faires, we observe people from diverse professional and academic backgrounds engaging with innovative designs and producing artifacts. Some of those makers are professional engineers, but many are amateurs practicing engineering skills through a process of learning by doing. Designing and building are partly skills of creative craftsmanship that can be acquired through experience. Anyone can be an engineer, "for we all have the principles of machines and structures in our bones" (Petroski, 1985: 11).[2] So, on the one hand, "making" and the "maker movement" are novel due to the democratized, collaborative, networked, digitized and user-oriented characteristics. Yet, on the other hand, "making" at its root is something familiar, a rediscovery of something that traces back to humanity's roots. "Making" and "engineering" are thus inextricably intertwined.

As Petroski (1996: 2) argued, engineering's methods "have been professionalized and formalized, and its essential calculational nature has been greatly enhanced by the electronic computer. But that is not to say that the skills and discipline required to do good engineering are totally different from those exhibited by craftspersons throughout human history." Engineers are as much the protagonists in the maker movement as in the science of the artificial (Simon, 1996). Further, the maker movement is one way to observe that the professional and formal barriers are increasingly being circumvented even while the ability for anyone to apply principles of engineering and to produce is spreading and accelerating rapidly. We illustrate this on the

[2] We acknowledge that technical aspects of engineering like stress analysis, fluid and thermodynamics, etc. require specialized training and education that are difficult to acquire through practical experience alone.

vertical axis in Figure 3: the democratization of innovation and the dynamics of the maker movement have enabled individual makers, shown in Cell C, to make artifacts and then attempt to bring them to market by creating new ventures (or licensing their designs to other firms), as shown in Cell D.

We turn now to the link between engineering and entrepreneurship. Koen (2003: 7) defined the engineering method – the design methodology used by engineers – as “the strategy for causing the best change in a poorly understood situation within the available resources.” Two things are noteworthy in this definition. First, the “best change,” or optimum solution as referred to earlier, is contingent on the purpose and context of the engineer as designer. It “does not pretend to be the absolute best in the sense of Plato, but only the best relative to the society to which it applies” (Koen, 2003: 19). Second, the engineering method bears a striking resemblance to Knight’s (1921) view of entrepreneurship as judgmental decision making about resources and investments under conditions of uncertainty (Foss & Klein, 2015) and resource constraints (Stevenson & Jarillo, 2007). Engineering deals with strategy through decision making and problem solving – in essence, with making judgments (Vries, 2005). Further, the engineering method is applied with uncertainty (Petroski, 2010: 186) using heuristics and rules of thumb. In these ways, the mental models and decision making of entrepreneurs and engineers overlap significantly. We posit that entrepreneurs creating engineering solutions under time and resource constraints can be equated to exercising judgment about how best to solve a problem. Judgment and entrepreneurial design, therefore, fall within the strain of entrepreneurship research that takes action as the unit of analysis (Foss & Klein, 2015; McMullen & Shepherd, 2006). Both entrepreneurship and making are interested in the design and implementation of solutions to problems, leveraging and coordinating heterogeneous resources under conditions of uncertainty.

The Philosophy of Technology

Engineering methods bridge the science of the artificial to the philosophy of technology, which shares much common ground that is valuable for both entrepreneurship and making. The philosophy of technology[3] has its root in the Greek *techne* (Mitcham, 1994), or the knowledge or skill to produce something. Like the science of the artificial, the philosophy of technology distinguishes technology from nature because "(e)ngineering has as its principal object not the given world but the world that engineers themselves create" (Petroski, 1985: 2). Further, the philosophy of technology also emphasizes purposeful action by defining "activity as conduct involving meaning" (Verkerk, Hoogland, van der Stoep, & Vries, 2015: 196).

Four key themes have emerged in this philosophy: "technology as artifacts, as knowledge, as processes, and as part of our being human" (Verkerk et al., 2015: 3). We connect each of these themes, in turn, to the maker movement. Technology as *artifacts* refers not so much to the tools of production as to the output of production. Similar to the observations on the materiality of artifacts above, in the philosophy of technology there is a "primacy of reference to the making of material artifacts" (Mitcham, 1978: 230), which coincides nicely with what makers do. Regarding technology as *knowledge*, there is a difference between technological knowledge – 'what ought to be' – and scientific knowledge – 'what is' (Vries, 2003). This design knowledge of 'what ought to be' combines with the knowhow of how to bring it about by integrating multidisciplinary knowledge in order to design new products (Verkerk et al., 2015: 124). One of the primary aims of makers is to acquire new knowhow (Lang, 2013), which leads them to implement design knowledge.

[3] The philosophy of technology is a young field, albeit older than entrepreneurship, and similar in still sorting through aspects of its distinct scholarly identity. It began to emerge as a field in its own right in the late nineteenth century through the work of Ernst Kapp (1808-1896) and Karl Marx (1818-1883) (Mitcham in Verkerk et al., 2015: xiii).

Technology as *processes* refers to the theory of methods, the way in which things come into being from design to production. The emphasis on process, not just products is important. As Koen observes, "Most people think of the engineer in terms of his artifacts instead of his art" (2003: 8). For many makers, the emphasis is more on the art of making than on what artifacts are made because, for them, "the problem and the solution develop together" (Cross, 2011: 11 in Williams et al., 2014). Technology as *part of being human* refers to the human will, worldview and the values people employ while being technically busy. Verkerk et al traced the modern history of technology and production "from dehumanization to human measure" (2015: 156) They referred to the 'complete task' – the idea that a person should complete an entire task, not just part of it as in Henry Ford's dehumanizing assembly line – as the core concept of sociotechnology. This also is what makers do – completing tasks of their own choosing, finding meaning and fulfillment in participating in the entirety of the making process.

Through each of the above four themes runs the thread that technology is collaborative and *social*, a point we also made in Figure 1 with our emphasis on community. With its grounding in the artificial, the philosophy of technology may be considered as distinct from the social and natural sciences. Yet, as the social technology literature (Bijker, Hughes, & Pinch, 1987; Garud & Karnøe, 2003; Simon, 1996) explains, the development of innovations is usually done in collaboration with others. From a theoretical perspective, this can be described as collective "supraindividual, interaction-driven experimentation processes" through which new ideas are generated as "individuals recombine the different practices into which they have been previously socialized in their respective fields" (Furnari, 2014: 448). In practice, by engaging in global networks or in local maker spaces, makers collaborate in a community of technological practice (Constant II, 1987). The philosophy of technology emphasizes the collaborative and social aspects of design, with engineers working in design teams to meet the needs of groups of customers. Other scholars have offered similar insights about the social meaning of technology in the context of the maker movement (G. Yang & Lindtner, 2014).

By participating in the maker community and learning to apply both the technological and knowledge resources of the movement, maker entrepreneurs become personifications of the reversal of the "scientification of the design process" that led to functions like marketing, sales, design, and production to be specialized and separated (Verkerk et al., 2015: 156). In short, the makers and their making are socially constructed. Like engineering, the practice of making is a social endeavor that is interdependent with a larger social system and its goals (Petroski, 1996: 5–6), such that individual makers are embedded in a “relational system of interaction between individuals and collectivities” (Kroeber & Parsons, 1958: 583 in Kim et al., 2016). Mitcham (1994: 276) captured this dynamic, as it pertains to the philosophy of technology, by pointing out that “technological engagements are not just technical but have an immediately and intimately social dimension.” The philosophy of technology allows us to bring more attention to what makers do and under what conditions they bring things to market with commercial value. For entrepreneurship scholars more broadly, the philosophy of technology can help provide a more intricate understanding of technology as neither merely a black box of production nor a mysterious force of disruption, but also a recognizable theme of interest for scholars related to knowledge, process and human interaction.

DISCUSSION AND CONCLUDING REMARKS

Our goal has been to present a rationale for the maker movement as an area that will be a fruitful new avenue of research for entrepreneurship scholars. In doing so, we provided an overview of the maker movement and the dual identities of makers as engineers and entrepreneurs. Further, we built upon recent literature connecting entrepreneurship to the science of the artificial (Sarasvathy, 2003; Simon, 1996; Venkataraman et al., 2012), and extended that discussion to the engineering method and the philosophy of technology. Drawing from these foundations, we developed a theoretical framework to analyze who makers are and how they bring their creations to market through design of two types of artifacts – products and businesses.

Maker entrepreneurs exercise design across the design plane and all along the value chain, from making new product solutions to novel production approaches and locations to innovative channels of distribution. As makers, they design artifacts, new ways to collaboratively create them and new purposes for their use. As entrepreneurs, they design firms, resource combinations and ways to see and approach market opportunities. Whether it is designing material artifacts, designing market opportunities or even designing demand itself (Christopher & Ryals, 2014; Venkataraman et al., 2012), the purposeful action of design can offer invaluable possibilities for research. Taking the study of entrepreneurship as a study of action (Dimov, 2011; Foss & Klein, 2015; McMullen & Shepherd, 2006), a similar approach can be taken with engineering in that “design is the unique, essential core of the human activity called engineering” (Koen, 2003: 28). Design and engineering are both technological – concerned with how an artifact works – and social – concerned with why it is built and how it will benefit society. Good design puts the user of an artifact at the center of its focus similar to an entrepreneur’s focus on customer needs.

The design plane is a useful framework for analyzing the connection between the maker movement and entrepreneurship because it allows for future research streams at multiple levels. Exploring research opportunities along the design plane will contribute to entrepreneurship scholarship at the theory and empirical levels and will answer the call of various other fields that are looking for the contributions of entrepreneurship scholars to the maker movement discussion (e.g. Waller & Fawcett, 2014). We briefly consider four of these research opportunities here.

First, nascent entrepreneurship prior to firm formation and market entry is an important research topic with data difficult to collect (T. Yang & Aldrich, 2016). Under what conditions do amateur makers create products with high commercial potential? How do the resources and dynamics of the maker movement affect those conditions? Under what conditions does entrepreneurial intent influence engagement with the maker movement, and under what conditions does participation as a maker influence entrepreneurial intent? How does an individual maker's prior expertise regarding artifact creation or the use of engineering methods relate to entrepreneurial outcomes?

Second, maker spaces offer opportunities to observe and survey individuals and groups at various stages of product formation and intentions regarding commercialization. Is the prevalence of nascent entrepreneurship among maker space participants different than in the general population? To what extent do collaborations and learning within the maker community impact alertness to entrepreneurial opportunities or the likelihood of enacting them? To what extent does the maker community fulfill resource needs for product design, testing, production and distribution?

Third, we have emphasized the technological tools as a unique feature of the maker movement for innovation. Makers must gain knowledge and expertise in the use of these tools through formal or informal knowledge sharing. Does the breadth and depth of knowledge regarding the technology available alter entrepreneurial behavior? Are there patterns of resource use or collaboration with others that are associated with greater innovation, commercialization and firm growth?

Fourth, research opportunities are not limited to the individual maker level. Important research questions can be explored within large companies, current industry practices and at institutional levels. For example, under what conditions do corporations turn to the maker community (professionals or amateurs) rather than their own R&D laboratories for potential sources of innovation? For policy makers, under what conditions do the technology, community and spaces of the maker movement affect economic growth?

It is our hope that the answers to these and other questions that emerge from additional research will make the maker movement important for theory development and entrepreneurial practice. For management and strategy scholars, "the future of fabrication has the really interesting implication of turning consumers into creators and, as a result, into competitors of incumbent companies" (Gershenfeld & Euchner, 2015: 18). With the dynamics that are presently attempting to disrupt the producer innovator model (Baldwin & von Hippel, 2011), this future is taking shape now and it is a compelling field for entrepreneurship research. Like the effectuation of an entrepreneur or the experimentation of a maker, our goal has been to offer a vantage point and initial framework for further scholarly exploration. In designing a field of research such as this, we keep in mind Simon's (1996: 163) guidance for setting our agenda, "The idea of final goals is inconsistent with our limited ability to foretell or determine the future. The real result of our actions is to establish initial conditions for the next succeeding stage of action."

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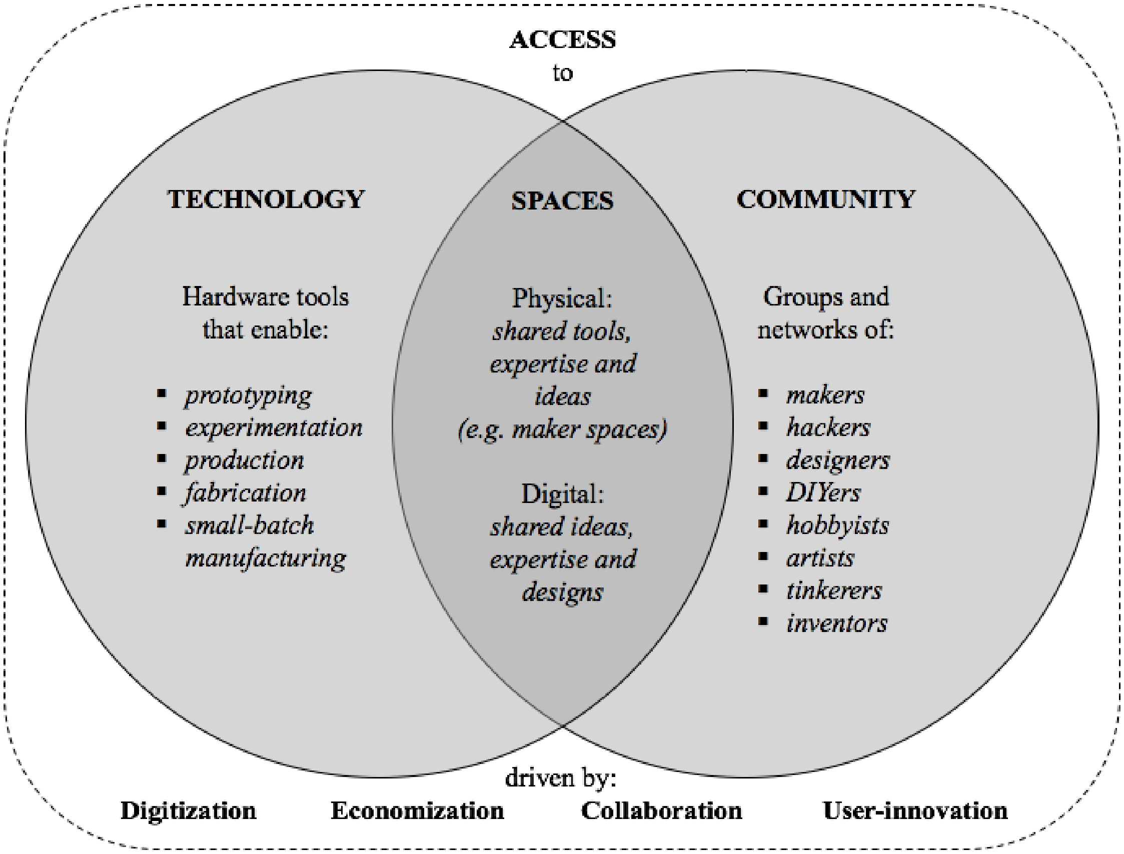

Figure 1. The Key Components of the Maker Movement

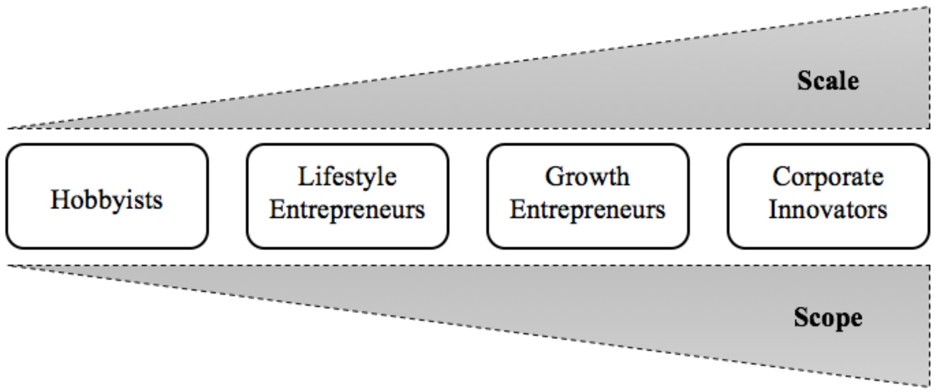

Figure 2. Increasing Scale and Scope of Makers in Entrepreneurial Intent and Action

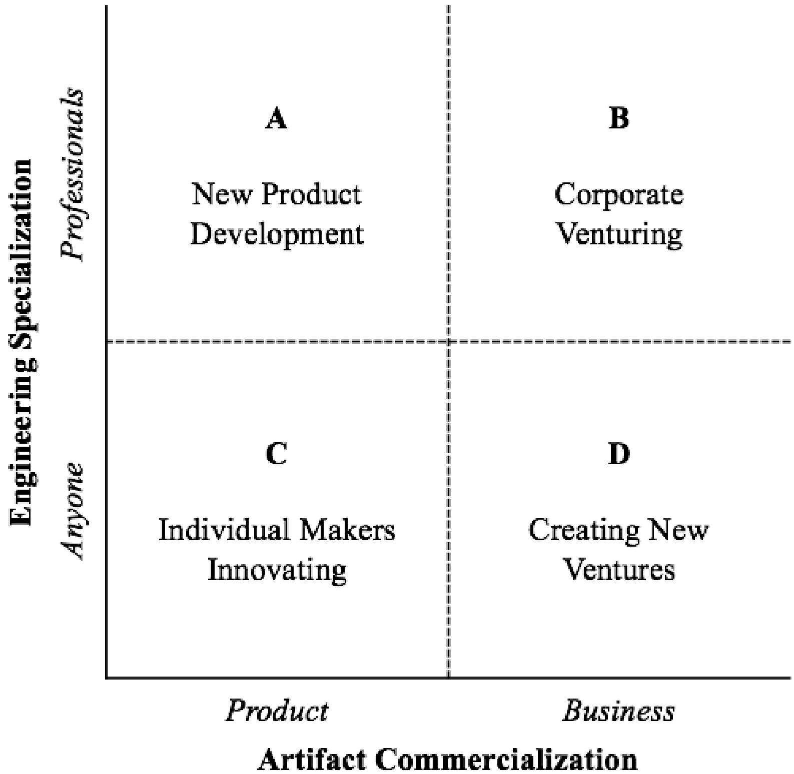

Figure 3. The Design Plane