Introductions to Making at a Community Fab Lab: Experience and Perspectives

Robert E. McGrath
Champaign Urbana Community Fab Lab
Urbana, Illinois
[Draft: 22 April, 2013]

Abstract

Digital technology is enabling new forms of community, new forms of expression, and changes in the living culture of contemporary life in many ways. One example is the emergence of local community-based fabrication spaces. This paper discusses one such space is the Champaign Urbana Community Fab Lab (CUCFL), which deploys a combination of technical, human, and social resources to develop local technological capabilities and opportunities. The CUCFL community is also connected to a network of like-minded Fab Labs and Maker spaces across the planet, as well as global markets and opportunities. These digital connections enable broad knowledge sharing, exchange of designs, and discovery of expertise.

The success of the CUCFL and similar labs depends on a combination of technology, a local community organization, and an open culture of learning, teaching, and sharing. All these elements are critical. These community labs also have significance beyond the local users and specific technologies, they are models of democratized technology, and harken back to earlier humanist workshop traditions, reintegrating technology, art, business, and community.

The paper discusses the technical and social background of personal fabrication, and the emergence of local community maker spaces. Then we consider one example of a local community-based Fab Lab in some detail, and then concludes with implications of this phenomenon.

1. Introduction

Digital technology is enabling new forms of creative and scholarly communities, new forms of expression, and augmenting the living culture of contemporary life in many ways. Contemporary technology enables enhancements to existing techniques, some new methods (such as pattern recognition and data mining), new forms of expression, and the adoption of new approaches to old problems of creation, dissemination, and communication. Many of these ubiquitous digital technologies have reached wide audiences beyond traditional engineering, scholarship, and art, opening the way for "humanistic" practices which are reintegrating with the living culture of contemporary life in many ways (Edwards, 2008; Gauntlett, 2011; Kelly, 2010; Shirky, 2010).

One such reintegration has emerged around *digital fabrication* technology, especially in the form of *personal fabrication* and local community fabrication spaces. This technology is widely viewed as revolutionary, potentially transforming the global industrial and consumer economy (Anderson, 2012; Gauntlett, 2011; Gershenfeld, 2005; Mota, 2011; Rischau, 2011).

The availability of personal fabrication technology, for design and realization or products, opens the way to the same transformations as seen in the realm of "bits", now in the realm of "atoms", including global scale peer-to-peer sharing, and the exploitation of "fat tail" phenomena.

As with any revolution, we will find evidence of it in local communities. This paper considers a local community-based Fab Lab which combines several technical and social approaches to we are developing an approach to fostering collaboration and creativity. The Champaign Urbana Community Fab Lab (CUCFL) combines technical, human, and social resources into a community-building process to develop local technological capabilities and opportunities. The CUCFL provides access to a suite of digital technologies access to knowledge necessary to use the technology that were not previously available to people, outside relatively privileged settings such as University labs.

The CUCFL is building a community of makers, dedicated to learning and teaching, with a consciously inclusive ethos. The lab has successfully welcomed many into our community of makers through an active learning environment within a supportive and friendly environment. The volunteer ethos in which everyone, not just a privileged elite, is a creator, a learner, and a teacher has encouraged people to discover just how much they know, and how much then can contribute. The CUCFL community is also connected to a network of like-minded Fab Labs and Maker spaces across the planet, as well as global markets and opportunities. These digital connections enable broad knowledge sharing, exchange of designs, and discovery of expertise.

The success of the CUCFL depends on a combination of technology, a local community organization, and an open culture of learning, teaching, and sharing. All these elements are critical, and to date, have sufficed to sustain the lab. Community fab labs have broader significance, beyond their local users and specific technologies. They are models of democratized technology, which may have profound social, education, and personal effects that change communities, economies, and individuals. Interestingly, it can be argued that a community fab lab harkens back to earlier humanist workshop traditions, reintegrating technology, art, business, and community.

The paper is laid out as follows. Section 2 discusses the technical and social background of personal fabrication, and the emergence of hundreds of local community maker spaces. Section 3 considers one example of a local community-based Fab Lab in some detail. Finally, Section 4 concludes with some implications of this phenomenon.

2. Overview of Digital Fabrication Technology

Recent decades have seen the rise of *digital fabrication* technology, through which designs are created with CAD/CAM (Computer Aided Design/Manufacturing) software, and realized through computer controlled fabrication machinery. Digital fabrication has significant and fundamental advantages for design and manufacturing in many situations (Anderl, 2003; Rehsteiner, 2003), and these technologies have reordered the industrial economy.

For more than a century, goods have been mass-produced through a set of specialized roles including *consumer*, *designer*, *distributor*, and *manufacturer* (Pine, 1993). In this arrangement, mass production differs from low volume, bespoke fabrication, in that the ultimate consumer (user) and the design team generally never meet, let alone collaborate

(Morris, 2009). With communication through statistical and market studies, these industrial design processes do not necessarily accommodate the possibility of the user altering the design, other than a few predetermined choices of color or patterns. While the number of options and selections may be very large (as is the case for automobiles), each product is extremely similar to the rest of the line. This has been aptly termed *mass customization*—mass production of modular product lines (Davis, 1987; Pine, 1993; Rischau, 2011).

Digital fabrication technology has led to the emergence of inexpensive, ubiquitous capabilities, termed *personal fabrication*. Personal fabrication promises to reorder industrial design, fabrication, and distribution, with potentially profound economic, social, and cultural effects.

To understand these developments, it is important to see the fundamental importance of "being digital" in this case. Two aspects of industrial production are fundamentally affected: design and fabrication. In addition, the availability of personal fabrication technology has led to the emergence (or perhaps, renaissance) of informal, local DIY "maker" spaces, outside the conventional industrial organization and economy.

2.1. The Importance of Being Digital

Manufactured products are designed by humans. *Digital design* enables one or more person to visualize and precisely specify products, including three-dimensional objects ranging from individual parts through assemblies and whole structures. Digital designs may be drawn by hand, created by computer simulation, may incorporate data from two- and three-dimensional imagery, or, most likely, will use combinations of these data sources. A digital design process can also incorporate other sources of data, such as previous designs and distant collaborators.

The resulting designs are *digital*, because the design is represented as digital data, stored in files, images, and databases. The digital data captures the design in a form that can be modified or combined with other designs, by human designers or computers. In general, the design data can be processed, shared, or stored for later use, using many techniques, techniques that cannot be applied to non-digital designs.

For example, digital designs can be algorithmically manipulated in a variety of modes, including:

- Simulation and analytic analysis (e.g., to model the properties of materials and structures),
- Application of heuristic knowledge (e.g., recommended limits for human comfort), and
- Parameterized and generative processes (e.g., to instantiate components from a family of related designs).

When a *design* is complete, it can be *fabricated* by humans or machines. When a *digital design* is complete, it can be *digitally fabricated*: the design (data) that describes the product can be sent to a variety of computer-controlled machines, which may use subtractive or additive methods to create objects from a variety of materials. These machines are *programmable,* with the digital design as the program, and therefore capable, in principle, of creating any object that can be designed. Just as general-purpose digital computers have replaced many purpose-built devices, digital fabrication uses general-purpose machines to replace purpose-built manufacturing systems.

Digitally controlled systems enable extremely precise and consistent fabrication, which has many crucial advantages, including:

- High accuracy and lossless replication (because the digital design can be represented to any required level of precision, and will never degrade)
- Optimization and reuse of previous designs, as well as "just in time" manufacturing
- Transfer of designs to alternative machines and materials (simply by transferring the data files)
- Detailed documentation of designs (i.e., the digital data itself is a very detailed representation of the essence of the design)

Digital fabrication has become an essential technology, enabling coordination of production, supply, and transportation, improving efficiency, quality, and profit.

Even more significantly, digital fabrication technology crosses the boundaries between physical and virtual worlds in an important way. Once something (in this case, the design for making an artifact) is digitized, it becomes possible not only to manipulate it, but also to mix, remix, and share it. Digital design and fabrication not only enables efficient production for conventional factory production, it opens the way for several radically new means of production, not only to manufacture on demand, but also to fabricate at a location of choice, be it a factory, retail store, or home.

2.2. Digital Design

Philosophically, we should recognize that the *design itself* is an important object, in and of itself (Lessig, 2008; Plotkin, 2009; Shirky, 2010). A design is a knowledge artifact that explicitly captures *how to make a product*, along with implicit information about what it is for, what it relates to, why it is wanted, and so on. Creating a design is, in part, a process for representing this knowledge in a form that can be used to create the product. Conventionally, a design may be represented by words, drawings, equations, and physical models.

A *digital design* for an object is a collection of data which describes the object to be built in an essential way: *the design data is sufficient to reproduce the object beyond its original time and place*. A digital design does more than show you what the object is or how to use it; it is a precise, executable plan to *actually make it*. Therefore, a high quality digital design contains information that is difficult to fully describe in blueprints and instructions: words are ambiguous and incomplete, and drawings have finite precision and resolution, but a digital design may describe everything needed to create the object.

An even more important side-effect of digital design and fabrication comes from the easy transmission of the bits. Specifically, there is less reason to stockpile and transport manufactured products, because you can (digitally) stockpile and transport the *design itself* much easier and cheaper, and then make the object when and where it is needed.

To understand the significance of digital design objects, consider how digital sound recording captures something essential about a musical performance. The recording enables a performance to be recreated beyond its original time and place. Furthermore, a high quality digital recording contains information (e.g., idiosyncratic variations and errors by performers, or environmental effects on the sounds) that would be very, very difficult to accurately represent in a score or written description, and also would be very difficult to reproduce in a recreation of a piece (assuming you wanted to reproduce the original performance).

The analogy of digital designs to music recording and other digital objects is actually very broad. First, the ability to represent a product design digitally changes the way products can be distributed. Digitized music has revolutionized the business of music, overthrowing corporate empires and wiping out local record shops: it is so easy for people to disseminate digital music—everyone can do it (Lessig, 2008; Levy, 2006). (The same can be said now for video and soon for books.) Digital music sharing shows up in two major forms, digital commerce, and networked communities of interest (which are not mutually exclusive).

Just as we can purchase music, video, and books that are delivered digitally to be "played" wherever and whenever we desire; it is possible to deliver the *design* for an object, which can be manufactured anywhere the proper "player" is available. This means that factories can be located anywhere, resulting initially in outsourcing around the world (which is great for manufacturers), but leading eventually to very local production, e.g., right at your local store (which is great for customers).

Note that distribution of digital music, video, and books requires the consumer to have the ability to "play" the data. For digital designs, the "player" is the digital fabrication system, i.e., you need to have a personal factory. But, just as digital music players have become cheap and ubiquitous, digital fabrication systems are becoming cheap and available. This parallelism is not a coincidence: they are driven by and benefit from the same technology and cost improvements. Table 1 suggests the analogies between digital music and digital fabrication.

Table 1. Analogy between Digital Music and Digital Fabrication

Digital Music	**Digital Fabrication**
Digital composition/mixing/recording *(making the master track)*	Digital Design *(making the master plan)*
Performance *(skilled rendition of the piece)*	Manufacturing *(skilled rendition of the piece)*
Digital player *(tools of the trade)*	Digital Fabrication Equipment *(tools of the trade)*
Music Download *(distribution via internet)*	Design Download *(distribution via internet)*
(Note: this is where money may change hands)	

2.3. Personal Fabrication

In recent years, digital fabrication technologies developed for mass production and precision engineering have developed to the point that the entire workflow is now also available in inexpensive, open technology potentially available to anyone (Gershenfeld, 2005; Mota, 2011). This development follows the trends for all digital technology, as powerful computation, storage, displays, and networks have become ubiquitous and cheap. The result has been the opening of the opening of the era of *personal fabrication*, as imagined for many years in science fiction (Doctorow, 2009; Frankowski, 1987; Haldeman, 1974; Stephenson, 1995; Stross, 2004).

Personal fabrication is heralded as revolutionary; potentially reordering the manufacturing economy, similar to the ways that digital networks have already transformed the music, video, and print industries. With inexpensive fabrication equipment, it is possible to buy the *design for a product*, and make it yourself. Low cost personal fabrication could make possible peer-to-peer exchange, directly buying and selling manufactured goods without factories, stores, or large-scale distribution networks. And, since personal fabrication is small scale, the goods could be both just-in-time and highly personalized, and small enterprises can serve local or global customers (Anderson, 2012; Gauntlett, 2011; Johnson, 2010; Mota, 2011).

The existence of personal fabrication technology raises many questions about the relationship between designer, producer and consumer. If each person can, in principle, create and fabricate their own stuff, what is the role of the designer (Rischau, 2011)? What do we need large factories, freight transport networks, or local retail stores for? If it is impossible to distinguish an original from a copy, because there *is* no difference, then ownership of the rights to the design is crucial, and the ability to actually make products is a ubiquitous commodity except for bespoke luxury items.

But, personal fabrication also increases demand for personalized products, and specifically for designs that allow customization. This is an opportunity for designers to attract customers by providing opportunities for personalized creation of products. Customers may be engaged through well-designed computer interfaces with corresponding underlying processes, that encourage customers to participate in the design of the product (Rischau, 2011).

Naturally, such a radical economic transformation is not so simple. Personal fabrication will not replace all manufacturing (Johnson, 2010). Digital fabrication has certain irreducible problems that must be solved in the real world: input materials (plastic, metal, etc.), energy inputs, and waste output (e.g., smoke). Working with paper, wood, or plastic can be done with moderate energy inputs, and with little waste management, but forging, cutting, or welding metal requires significant energy, and produces dangerous by products that must be controlled. Consequently, while there are many products that could very well be delivered to you as digital designs that you “run off” when you want them; not everything is easy to fabricate, so some things will still require “industrial” facilities. In addition, business models and legal structures for personal fabrication have yet to be worked out. It took quite a few years of failures before digital music was “itunized” (Levy, 2006), and we can expect similar working-out of the process in the realm of “downloadable stuff” (Lessig, 2008; Plotkin, 2009).

Even more important than economic revolution, personal fabrication technology is transforming creativity—literally putting tools in the hands of workers. It is almost true that every individual can fabricate whatever he or she desires—provided he or she learns how to do so (Anderson, 2012; Gershenfeld, 2005). Humans have always made things—it’s a big part of what makes us human (D'Errico & Backwell, 2005; Renfrew, Frith, & Malafouris, 2009; Smithsonion Institution, 2013). There is a long history and tradition of craftwork, in settings of both "work" and "hobby" (Gauntlett, 2011), but digital fabrication provides a relatively low threshold for entry (hours rather than years to learn), along with potentially high quality results. Digital fabrication also tilts the table toward design skill, over manual dexterity, and fits naturally into networked society in all its forms.

2.4. Maker Culture

The availability of low cost digital fabrication technology combined with the technologies for digital community has led to the emergence of a variety of community-based social spaces in which thousands of non-professionals are now engaged in design, adaptation, and fabrication of objects. This is a "do it yourself" (DIY) culture, variously known as "makers" (Make, 2011), "fabbers", or "hackers", as well as Open Source Hardware (Open Source Hardware Association, 2013), DIYBio (BioCurious, 2013; Wohlsen, 2011), and other variations. In addition to school and home labs, world wide networks of community work spaces have emerged, including hundreds of Fab Labs (affiliated with MIT) (FabFolk, 2013; FabWiki, 2013; Gershenfeld, 2005) and independent Maker Spaces (HackerspaceWiki, 2013). Similar spaces are emerging under the aegis of schools, science museums, business parks, and public libraries.

These spaces deploy low-cost digital design and fabrication techniques in small, community-based workshops featuring an empowering and creative "do it yourself" ethos within a supportive, diverse, and multidisciplinary setting. These spaces are akin to older workshop or design studio traditions, rather than hyper-efficient mass production facilities. However, unlike a local workshop of an earlier age, fabrication labs are connected via the Internet to each other and the wider world. These connections enhance and magnify long existing creative drives, because knowledge can be shared in a very direct way: knowledge (i.e., designs) can be uploaded and then downloaded and executed (e.g., from (Shapeways, 2013) or thingiverse (Makerbot Industries, 2013)), thereby directly connecting local labs and individuals world wide (Anderson, 2012; Gauntlett, 2011).

For better or worse, advanced industrial technology is now in the hands of everyone (Anderson, 2013; Fountain, 2013; Instructables, 2013). This technology-driven culture has produced a burst of creativity, characterized by the sharing of design and knowhow, new modes for fabrication and distribution, and new digital services. These local community-based workshops are the critical piece in this development.

3. A Local Community Fab Lab: Think Globally, Make Locally

The Champaign Urbana Community Fab Lab (CUCFL) is a volunteer-operated, open community of people who like to design and make things (CUCFL, 2013a; Ginger, McGrath, Barrett, & McCreary, 2012; Watson, 2011). The CUCFL was founded in 2009 with seed money and in-kind contributions from the University of Illinois Urbana-Champaign campus and significant donations of time and skill from community volunteers. The CUCFL makes available to the community many resources, including skilled volunteers, computers, computer-controlled machines, and electronics assembly tools. These high tech tools, and an open, informal environment, make it possible for people of all ages and skill levels to learn to build virtually anything imaginable.

While situated on the University campus, the CUCFL's mission is to make resources available to the entire community. From inception, the CUCFL has had a special focus on introducing middle school and high school youth to making. The CUCFL is organized as an open, volunteer run organization, as expressed in the charter (CUCFL, 2013d).

The CUCFL is affiliated with the International Fab Lab Network that originated at MIT. The more than 140 member labs around the world are operated independently, sharing and cooperating through standards and a common vision (FabFolk, 2013; FabWiki, 2013). In addition to the MIT affiliated Fab Labs, hundreds of independent "Maker Spaces" and "Hacker Spaces" (HackerspaceWiki, 2013), which provide similar creative environments. In fact, there is a Makerspace in Urbana, less than 3 km from the CUCFL (Makerspace Urbana, 2013). These spaces are part of a large, informal global community of makers, who share a plethora of information and enthusiasm via the Internet.

The CUCFL is an example of how a local, community fab lab can be built and operated. This section discusses key features and activities of the lab including the community of volunteers, the do it yourself ethos, knowledge sharing, local and global communities. Together, these features have created to a successful lab, despite limited and uncertain financial support.

3.1. Who Does What in the CUCFL

The CUCFL is entirely volunteer operated, benefiting from hundreds of hours of skilled learning, teaching, and work from a broad range of individuals from the local community. The CUCFL has built a community of people with a range of expertise and a desire to share; volunteers who love to learn how to make things, and who love to share their knowledge with others. The community includes teachers, students, hobbyists, artisans, and others, who work together to imagine, design, and make; and to learn from and teach each other. On any given day you may find kids and parents, University students and staff, artisans, entrepreneurs, school teachers, and retirees; working side by side on projects of their own design. Students, staff, and faculty from many departments of the University participate in the lab, which also serves kids from youth groups, local schools, and home school groups; as well as hobbyists, handicrafters, inventors developing prototypes of new products, and artists exploring and fabricating new creations.

The CUCFL provides an environment in which everyone, including young women and kids from underserved communities, can imagine, make, and share; and can learn and, in turn, become a teacher. Many projects develop collaboratively in the lab, through free-wheeling discussion, experimentation, and iteration, which can produce eclectic explorations of academic, technological, and artistic concepts (e.g., (CUCFL, 2011f; R. E. McGrath, Rischau, & Craig, 2012)). The CUCFL hosts workshops and design sessions, such as a one-day "Fab Off", attended by participants from other Fab Labs in the region (CUCFL, 2011d), and a design workshop by visitor Federico Joselevich (CUCFL, 2012a). Some of the founders of the CUCFL have graduated from the University and gone on to create a local start up design and engineering companies partly inspired by their experience in the Fab Lab (Norden, 2013; The Product Manufactory, 2013).

3.2. How We Introduce People to Making

The CUCFL volunteers work hard to make the Fab Lab something you "do", not something you "watch". One of the most important activities of the Fab Lab is inviting new users to begin to make something. Many first time visitors view the Fab Lab as a somewhat alien environment, with an exciting but daunting array of high tech tools. At first, many people have little notion of what can be done, and might imagine that they are incapable of creating their own designs.

The CUCFL hosts informal introductory sessions for walk-ins and small groups. These sessions consist of an introduction to the lab, followed by a hands-on project, tutored by experienced volunteers. Based on the principle of "show, don't tell", the novice has the opportunity to, and is strongly encouraged to, design and make a simple object, such as a personalized key ring or sticker—to actually go through the process of making something *on the first day*. This experience is simultaneously empowering and an encouraging introduction into our community of makers.

The CUCFL also conducts similar workshops for local organizations focused on youth and education. These include youth groups (e.g., the Don Moyer Boys and Girls Club (Don Moyer Boys and Girls Club, 2013) and after school clubs from local schools) and adults (e.g., art teachers from a local school district), as well as University classes from several departments (Engineering, Library and Information Science, Media Studies, Gender Studies).

The CUCFL hosts a variety of explorations of design, materials and design. These have been led by local volunteers, University researchers, and visitors. These include from introductory tutorials (e.g., how to use Inkscape), explorations of technology (e.g., "Squishy Circuits" (CUCFL, 2011b), "Blue Platter Saturday" (CUCFL, 2011f), conductive ink (CUCFL, 2012c)) and eclectic "challenges" (e.g., a regional "Fab Off" (CUCFL, 2011c, 2011d, 2011e), "Hack a T-Shirt" (CUCFL, 2012b), and a design workshop led by a visiting scholar, Federico Joselevich (CUCFL, 2012a)).

Nowhere is the spirit of the CUCFL more apparent than the one Saturday per month "Kid's Hour" for ages 10-16, developed by the CUCFL Youch Council (CUCFL, 2013e). The group was the brainchild of a young volunteer, who is a home school student, and has, from the beginning, been run by the kids themselves. Some sessions are tutorials on specific topics, others are open sessions, and some may pursue group projects. Fifteen students have participated, with a typical session has 6-8 kids with adults watching, with at least two hours reserved for whatever the kinds want to try.

The first sessions were small projects that were designed to introduce the different areas of the lab. As the students become familiar with what can be done in the lab, the group works on more advanced projects as well as encouraging them to work on their own ideas. One of the best parts about having a day that is just for the young people is that they do not feel that they are competing with anyone else for the lab's resources. On that one day of the month the lab is all theirs (Howard & Howard, 2013).

As would be expected, the CUCFL participates in many local expos (CUCFL, 2013b) and also in the local Maker Faire (Urbana-Champaign Mini Maker Faire 2012). The CUCFL has also participated at the US and Fab Lab International conferences, and even hosted a temporary Fab Lab, transported to the 2010 Alaska Federation of Natives Conference in Fairbanks, Alaska

(Caldwell, 2010).

3.3. Knowledge Sharing, Expertise, and Tutorials

The CUCFL is a center for expertise as much as technology. Fab Lab volunteers are makers, but equally learners and teachers. We learn by doing, and by teaching, and in the CUCFL there is a strong spirit and ethos of curiosity, openness, sharing, showing, and doing together. There is pleasure to be found in making something, and it is surely a good feeling to admire and praise the work of others. Even more, it is a unique joy to creating something together that could not be made individually.

No single volunteer knows everything, but the "union" of all the knowledge in the CUCFL's community is truly astonishing, and continuously growing. Furthermore, volunteers are not only learning design and technology, they have the opportunity to discover their own ability and worth to the community. Every volunteer knows something they can contribute and teach to others, often to his or her own surprise.

Digital technology enables and encourages certain modes of sharing and community. The CUCFL volunteers "capture" some of the accumulated knowledge digitally, in the form of images, videos, wikis and other documents. These documents range from example works ("hey, look at the cool thing I made" (CUCFL, 2013c; R. McGrath, 2012)) to how-to tutorials ("How to make a simple press fit box" (CUCFL, 2011a)). Fab labs and maker spaces around the world are creating similar collections of knowledge, which are generally available to everyone.

Creating useful tutorials is very difficult, perhaps the most difficult challenge encountered in a Fab Lab. But digital fabrication allows a tutorial to include examples and templates which can be *directly* used for practice and learning. This, along with the open spirit of fab labs and maker spaces, encourages reuse and remixing of designs and the knowledge they represent. Many projects are inspired by the work of others, and makers may directly reuse digital plans to recreate a fun idea or modify to create a new variation. Ideally, the "debt" to the community is repaid when a modified or remixed creation is, in turn, "published" for all the world to use.

The CUCFL is an interesting example of a hybrid "space", which is simultaneously a physical and a virtual community. The digital resources and connectivity would mean little without actual machines to make things, and the machines alone would never be as useful without the expertise and exchange in the community space. In turn, the digital technology not only enables high quality fabrication, but also helps people to share and discover knowledge, and to participate in a world wide community of makers (FabWiki, 2013; HackerspaceWiki, 2013).

3.4. The "Fab Lab To Lab Fab" Initiative

In 2011, the global Fab Lab initiative proposed a challenge to see if labs could be created according to the power of ten. This problem asked the labs to consider if and how labs might be created at a series of scales, roughly designated by levels of cash outlay: $100, $1000, $10,000, etc.

Inspired by this challenge, the CUCFL, in collaboration with the Community Informatics program of the University of Illinois at Urbana Champaign, is creating a network of mini labs in a variety of local venues targeted at students from 8 to 18 years of age. This local network is loosely modeled on Global Fab Lab Network, and, in effect, extends it with another layer of “capillaries”. The initial partners are described in Table 2 and (Ginger et al., 2012).

Table 2. “Fab Lab to Lab Fab” Community Partners 2012

Community Partner	Description
Tap In Leadership Academy (Champaign, Illinois) (Tap In, 2013)	Tap In Academy is a 501(c)(3) dedicated to providing one-on-one mentor-tutoring and scholar-centered enrichment activities that encourage academic achievement, leadership skills and cultural awareness. By providing young scholars with equitable opportunities for intellectual, social, and emotional growth, Tap In fosters the kinds of competencies and lifestyles that lead students into four-year universities.
The Urbana Free Library (The Urbana Free Library, 2013b)	Named one of "America's best public libraries" in national rating surveys published by The American Library Association, The Urbana Free Library has earned a reputation for the quality of its collections and for outstanding service to patrons of all ages. The library is the very heart of community life in Urbana and continues a longstanding tradition of provision of public computing and digital information access.
Stratton Elementary School (Champaign, Illinois) (Champaign Unit 4 School District, 2013).	Stratton Elementary is a progressive learning environment that recognizes, respects, and supports the gifts, talents and diversity of students and community. They value and promote genuine collaborative relationships, social justice, and life-long learning for the success and enrichment of all. The Stratton Leadership Magnet School has a unique MicroSociety® curriculum that includes six strands: (1) Technology, (2) Academy, (3) Humanities & Art, (4) Citizenship & Government, (5) Economy and (6) HEART (giving back to society).

Both the CUCFL and the collaborative sites have a mutual set of responsibilities. The mini labs commit to use their resources in the promotion and development of skills and capabilities that align with the Fab Lab mission: personal growth, economic development and cross-cultural understanding. In return, each local mini lab receives a starter set of essential equipment and supplies that will enable the people at that site to create a variety of objects of their own design. The main CUCFL provides training, assistance and materials, including tutorials and starter project kits. As users develop skills, they will be able to use the larger capabilities of the main lab.

Our collaboration with the Urbana Free Library has been incorporated as part of their “Creation Tech” initiative (The Urbana Free Library, 2013a), in collaboration with the Urbana Makerspace (Makerspace Urbana, 2013) and UIUC Graduate School of Library and Information

Science. This new space will include a variety of digital resources along with programs to develop digital literacy and career skills.

3.5. Global Connections and Collaborations

Volunteers from the CUCFL have participated in the global Fab Lab network (FabFolk, 2013), participating in the world Fab Conferences, and the MIT Fab Academy (Fab Academy, 2013). In its four-year existence, the CUCFL has become recognized as a leading center for development this style of laboratory. We have received dozens of inquiries and visits by people interested in establishing similar labs around the world, through emails from Europe and the US, as well as walk-in visitors from Central America, US, and Europe.

The CUCFL provides advice to the Alaska Federation of Natives (AFN), and demonstrated a temporary Fab Lab at the AFN annual meeting in 2010 in Fairbanks Alaska (Caldwell, 2010). The demonstration, funded by the National Science Foundation, was a collaboration with the MIT Fab Lab's South Boston Center (The South End Technology Center, 2013). The program featured a temporary Fab Lab in a tent (deployed from Illinois to Alaska), and peer-to-peer sessions between young makers from South Boston and local kids from Fairbanks. This project may lead to development of several Fab Labs in rural Alaskan villages.

Volunteers from the CUCFL have provided advice to the Chicago Public Library's initiative to develop "Maker's Café" which will make these technologies available to everyone in the city (Institute of Museum and Library Services, 2012). This project is a collaboration of the Chicago Public Library and the Museum of Science and Industry (which already has its own Fab Lab (Museum of Science and Industry, 2013), as well as other community partners in the city of Chicago. The CUCFL has provided advice as well as tutorials and other educational materials (Ginger, 2013).

3.6. Status and Outcomes

Given that the goals of the CUCFL are broad and continuing, it is easy to find positive results and difficult to identify "outcomes". The key goals are developing communities and disseminating knowledge, not the creation of specific products, completion of particular projects, or deployment of a specific array of technology.

The CUCFL has a community of dozens of volunteers. A few volunteers have spent hundreds of hours over several years, many accumulating dozens of hours, and a wide community who participate on occasion. The CUCFL has hired several undergraduate student lab managers, and has contributed to University research of at least two graduate students (Ginger et al., 2012; Rischau, 2011) and two faculty members (Barrett, 2012; Cutcher-Gershenfeld & Lawson). The CUCFL also has a network of "champions", authoratative voices who advocate for the mission and practice of the fab lab, as well as providing strategic guidance and support.

The CUCFL volunteers include an astonishing range of skills and background, including:

- University students, faculty, and staff
    - many fields, including engineering, art & design, library and information science, computer science, social science, agriculture

- Local artists and entrepeneurs
- Local school teachers, at all levels
- Parents and families, including home school and enrichment groups
- Public librarians
- Retirees

The CUCFL has hosted a variety of workshops, roughly every six weeks, and the monthly Saturday "Kid's Lab" for ages 10-16 (CUCFL, 2013e). The CUCFL and other similar labs contribute to the development of human capital in the local community. Four CUCFL volunteers have completed the rigorous Fab Academy (Fab Academy, 2013), a virtual course with practical projects conducted at local Fab Labs around the world, include the CUCFL. These graduates, styled "gurus", have in turn, trained many local volunteers.

Several students involved in the establishment of the CUCFL have graduated and started local companies (Norden, 2013; The Product Manufactory, 2013). As students, these people profoundly influenced the culture of the CUCFL, and they are applying their eclectic skills to their commercial enterprise and economic development.

As part of the "Fab Lab To Lab Fab" initiative the CUCFL has contributed to the programs of the partner institutions. Each partner has its own history, goals, participants, and approaches. The interactions with the CUCFL are adapted to each organization and its people (Ginger et al., 2012).

These efforts contribute to the development of STEM education and digital literacy in the community. More than a dozen teachers from local school districts have visited the CUCFL for an introduction to the lab, including designing and making a simple project, and discussions about how they might integrate fab lab technologies and techniques into their curriculum. Several of the staff of the Urbana Free Library have visited the CUCFL and done introductory projects. This has led to further collaboration of the Urbana Free Library, the Graduate School of Library and Information Science at the University of Illinois, Urbana-Champaign and the Urbana Makerspace (Makerspace Urbana, 2013), as well as the CUCFL. The CUCFL provided some training for the library staff, and has loaned fabrication equipment, including a vinyl/paper cutter and a small 3D printer. In addition, the CUCFL acts as a "hub", where librarians and patrons can find advanced expertise, larger scale equipment, and a broader range of resources.

4. Implications

This paper has described the development of one community-based fab lab, in Urbana, Illinois. We reviewed the technical and social underpinnings, and presented recent activities. This final section considers the implications and importance of this work.

The CUCFL is an example of a digitally enabled community workshop. Its success depends on a combination of technology, a local community organization, and an open culture of learning, teaching, and sharing. All these elements are critical, and to date, have sufficed to sustain the lab.

The CUCFL is also a member of a world wide network of similar labs. The specific processes described above may provide useful models for the creation of similar labs. Indeed, the CUCFL has been asked for advice by groups wanting to create their own local labs, and the on-line tutorials have been used by other labs.

Community fab labs have much broader significance, beyond their local users and specific technologies. The fab lab and maker space are models of democratized technology and knowledge, which may have profound social, education, and personal effects that change communities, economies, and individuals. Moreover, it can be argued that a community fab lab harkens back to earlier humanist workshop traditions, reintegrating technology, art, business, and community.

4.1. A Local Community Lab, Connected Globally

The CUCFL is exploring a community-building process to develop local capabilities and opportunities. We believe this process has been successful, even within our limited resources. There are several components to this model, and we believe that each plays an important role in the overall success of the lab.

The CUCFL provides access to a suite of digital technologies that were not previously available to people outside relatively privileged settings such as University labs or well equipped technical schools. Equally important, the CUCFL provides access to knowledge necessary to use the technology, knowhow that will last beyond the obsolescence of the specific tools in the lab this year.

The CUCFL has created and strengthened human connections at many levels. Our fundamental approach is to build a community of makers, dedicated to learning and teaching, and creating together. With a consciously inclusive ethos, and an emphasis on service to youth, the CUCFL community has successfully cut across some of the invisible boundaries that exist within the local communities, bringing together people of many ages, backgrounds, and interests. The "Fab Lab to Lab Fab" mini labs and other outreach activities have promulgated knowledge and enthusiasm for digital fabrication into many settings in the community.

The CUCFL community is also connected to a network of like-minded Fab Labs and Maker spaces across the planet, as well as global markets and opportunities. These digital connections enable broad knowledge sharing, exchange of designs, and discovery of expertise.

Within the lab itself, the teaching and learning are embedded in a "show, don't tell" approach that makes the Fab Lab something you "do", not something you "watch". This active learning approach within a supportive and friendly environment has successfully welcomed many people who otherwise might never have attempted digital design or creation. The volunteer ethos in which everyone is a teacher has encouraged people to discover just how much they know, and how much then can contribute.

Financing has been a continuing challenge, and the CUCFL has always faced the question, "How long can this model be sustained?" To date, the answer appears to be: as long as the ranks of volunteers can be filled and refilled with people willing and eager to "do" the Fab Lab, we can keep it up forever.

4.2. Tools in the Hands of the Workers (and Everyone Else)

The CUCFL is as much about knowledge sharing and skill development as it is about specific technology or technologies. Access to technical tools is important, but knowledge often is more important (and durable), and the combination of both is essential. In the Fab Lab we learn how to create physical objects through design, understanding of materials, and skillful manipulation. This also leads to a deeper understanding of how technology works, and how technology is made. This complex array of mental and manual skills is an important set of twenty first century tools, tools which we are putting in the hands of the workers, with potentially transformative and revolutionary implications.

Digital fabrication has transformed manufacturing, enabling flexible, just-in-time manufacturing, and mass customization of consumer goods. The emergence of personal fabrication has the potential to reorder the industrial economy, possibly on a par with the industrial revolutions of the past. Among other transformations, it is becoming possible to not only manufacture on demand, but also to fabricate at a location of choice, be it a factory, retail store, or home, and to directly share and sell digital designs, to be built anywhere.

Personal fabrication technology coupled with on-line collaboration technology that enables open distribution of designs challenges the entire fabric of the mass production and consumer economy. The design becomes far more valuable than the workshop needed to make it, and a digital design can be shared and "mashed up" similar to any other representations of knowledge. For professional designers and manufacturing, this technology is a profound challenge: these technologies make possible, and, indeed call for, collaborative design. How will designers respond?

In addition to reordering the manufacturing economy, personal fabrication may also provide paths to sustainable local communities. The CUCFL fosters development of skills, knowledge, and innovation within our local community; while digital fabrication offers global reach. Innovative ideas can be realized and built into business within a local community, which can expand to world-wide distribution.

4.3. An Educated Workforce, Digital Literacy, Informed Citizenship

Like personal computing, personal fabrication is a "home version" of extremely important industrial knowhow. Young people (or anyone) who learn how to design and create physical objects are learning a collection of cognitive and manual skills that are increasingly vital career skills. For this reason, many STEM programs have enthusiastically embraced digital fabrication as part of education programs at all levels (Mack, 2013; The I-STEM Education Initiative, 2013).

For this reason, personal fabrication is rapidly gaining a key role in formal and informal education. A manufacturing economy cannot be sustained by a workforce with insufficient knowledge of how to make physical objects and little understanding of how technology works. Community workshops such as the CUCFL have become important in the face of a combination of budget constraints, technical change, and pedagogical fashions that have nearly eliminated "vocational" education in many middle and high schools.

In addition to introducing digital fabrication to STEM and vocational curriculum, Fab Labs such as the CUCFL embed the technical skills within an informal learning environment which also fosters cross-generation and community-wide sharing and collaboration, thus broadening participation and opportunities, and strengthening the overall social capital.

From a slightly different perspective, learning and teaching in a fab lab can be argued to be a valuable contribution to the development of “digital literacy”: skills essential for participation in contemporary society. Conventionally, literacy is viewed as a social good and human right, which involves an array of conceptual skills, not limited to reading and writing (e.g., (Street, 2005; UNESCO, 2004)). Recently, these concepts have been extended to include skills for dealing with information using a variety of technologies (e.g., (Lankshear & Knobel, 2008)). Taking this perspective farther, a Fab Lab enables literacies that build upon creative engagement with information in the creation of expressions that take the form of physical objects, not just digital artifacts that appear on a screen (Ginger et al., 2012).

Given their historic role in disseminating literacy, it should not be surprising that one of the most active partners of the CUCFL is a public library (The Urbana Free Library, 2013a). To date, it is not clear in what ways digital fabrication will ultimately fit into the already over-taxed programs of public libraries (Kroski, 2013), but the CUCFL is vigorously exploring this question with our local librarians.

More generally, understanding of technology, especially the ability to fix, modify, and create your own objects, can be argued to be a critical aspect of savvy citizenship in the twenty first century. Experience in the Fab Lab may work towards demystifying the black boxes so rampant in our world today (Ginger et al., 2012). Many people have little understanding of how the inside of a computer works or what takes places behind the scenes as a computer file is created.

The Fab Lab encourages digging beneath the surface of technology to discover cause and effect processes, raw and processed materials, and the hidden order inside the covers. Opening the lid of the vinyl cutter in order to trade out the blade and load the cutting mat helps to dismantle small fears that could eventually accumulate to the debilitating levels often seen in older people when they try to learn how to use computers. Selecting a piece of acrylic to make something is a deep lesson in materials, design, and perhaps even recycling. Watching the laser precisely cut out a key ring you designed is a thrilling lesson in where key rings come from.

These experiences in making teaches us many lessons, letting use see deeper. This process of rejecting the surface world and peering beneath the surface of technologies is key to critiquing them and mastering them to make them their own (Illich, 1973).

4.4. The Humanistic Discipline of Making

Digital fabrication, especially in a local community workshop such as the CUCFL, is more than an industrial training exercise that creates better citizens and new businesses. A community Fab Lab combines the model of the humanistic workshop of earlier centuries with digital communities of the twenty first century. In this way, these labs embody a new burst of humanistic culture, “reintegrating” (to borrow a term from David Edwards (Edwards, 2008)) science, economics, art, and everyday life. This reintegration takes many forms, by enabling new forms of creative and scholarly communities, creating new forms of expression, and enriching the living culture of contemporary life in many ways.

Digital technology itself is revolutionizing both the study of Humanities and the practices of “humanistic” disciplines (Berry, 2012; Gold, 2012; Schreibman, Siemens, & Unsworth, 2004). Contemporary technology enables enhancements to existing techniques, some new methods for scholars (such as pattern recognition and data mining), new forms of expression, and the adoption of new approaches to old humanistic problems of preservation, dissemination, and communication.

Humanists, like many other communities, use ubiquitous digital technology to enhance physical communities, and to create virtual communities (such as HASTAC (HASTAC, 2013), CSDH/SCHN (CSDH/SCHN, 2013), the Pool (New Media Collective, 2013), and DIY of all kinds (Gauntlett, 2011)). These digital communities with a deliberately humanistic ethos may be valuable models for other electronic communities, through conscious attention to democratic and humane practices.

Digital technology has also enabled new forms of expression, new varieties of old forms, or new mixes. These include new media (Craig, 2013; Kreuger, 1991; Sherman & Craig, 2003), newly democratized modes of distribution (such as YouTube (YouTube, 2013) and "Self Publishing" (e.g., (Amazon, 2013; Blurb, 2013; Lulu Press, 2013)), "augmentation" pf performing arts (e.g., (Latulipe et al., 2010; Schiphorst, 2009; Smith, 2011)) and exotica such as (Fluidforms, 2011), (Mazalek et al., 2011) or (Cheok et al., 2008).

Many of these ubiquitous techonolgies have reached wide audiences beyond traditional scholarship and art, opening the way for humanistic practices which are reintegrating with the living culture of contemporary life in many ways, including syntheses such as "ArtScience" (Edwards, 2008), "serious games" (gameful.org, 2012), and "Alternative Reality" (McGonigal, 2011), and community work spaces (e.g., "Learn to Teach, Teach to Learn" (PBWorks, 2012), community gardens such as (Omaha Sprouts, 2013)).

The CUCFL and similar community-based labs are examples of such reintegration. In our lab we are developing an approach to fostering collaboration and creativity. With an emphasis on "making", we recapitulate the focus of ancient workshops on the personal transmission of knowledge in small, cross-generational settings. Incorporating digital design and fabrication instantiates a form of participatory media which may go far beyond electronic texts and images. The world wide network of makers ties the local to the global, and connects individual humans as equal and valuable partners in the larger enterprise.

The products of the Fab Lab bridge and blur the lines between everyday useful objects, advanced technology, and fanciful play. Many of the projects in the CUCFL are most easily called "handicrafts" or folk art—objects that have little economic value or social purpose, but which are done for "just for fun" or as a personal expression. Yet other projects are eminently pragmatic; such as scientific instruments or prototypes for new products. The CUCFL is also the site for cross-discipline explorations that are difficult to categorize (e.g., (CUCFL, 2011c, 2012c; R. E. McGrath et al., 2012).

While digital technology appears to be central to the CUCFL, a closer look reveals that human community and creativity are the real heart of the matter. Not only are the products eclectic, the community is quite diverse. In a fab lab, everyone is a "maker", and a "learner", and a "teacher", regardless to whatever roles and labels may be applied elsewhere. This boundary crossing is both a reintegration of the social structure, and a reintegration of the roles of individual humans—which is the essence of humanism.

4.5. "I Made It": Personal Creativity and Agency

Beyond the technical and economic implications, experience in these technologically enabled community work spaces can have profound and exciting psychological and cultural effects. In a fab lab, people, especially young people, may learn a fundamentally empowering lesson: they too can be a creator of things. By combining ideas and information, they can create real world objects that they can hold (and show and trade and whatever they want). Thus, they are able to influence the world around them. Everyone involved may experience this empowerment: students, teachers, and volunteers.

At bottom, this personal empowerment is the beating heart of the a community fab lab. It is thrilling when a kid's face lights up and he or she holds up an object and says, possibly for the first time, "*I* made this". And that is only the beginning—the kids inevitably teach other kids (and adults).

Acknowledgments

Thanks to Betty J. Barrett, Jeff Ginger, Virginia McCreary and for reading and discussing the drafts of this paper. Thanks to all the volunteers, especially Gary and M. K. Watson, and Dean Rose, who make the CUCFL possible.

Thanks to Isabella and Jeff Howard organizers of the Fab Lab Kids hours and the Youth Council.

This work was partly supported by the Office of the Provost, Office of Public Engagement, the Center for Digital Inclusion, and the Institute for Computing in Humanities, Arts, and Social Science (I-CHASS) of the University of Illinois, Urbana-Champaign. Additional loans and in-kind donations have been provided by several units of the University, including the Graduate School of Library and Information Science, The School of Art and Design, and the National Center for Supercomputing Applications.

The demonstration at the Alaska Federation of Native Conference was supported by the National Science Foundation **Arctic Social Sciences Program Awards Grant, 2010:** "AFN Fab Lab Demonstration Project," Alan Craig, PI, EAGER 490100.

References

Amazon. (2013). Self-Publish with Us. from http://www.amazon.com/gp/seller-account/mm-summary-page.html?topic=200260520

Anderl, R. (2003). New Information Technologies in Industrial Activity of the Enterprise (IAE). In A. Dashchenko (Ed.), *Manufacturing Technologies for Machines of the Future* (pp. 461-514). New York: Springer.

Anderson, C. (2012). *Makers*. New York: Random House.

Anderson, C. (2013). DIY Drones.   Retrieved 12 February, 2013, from http://diydrones.com/

Barrett, B. (2012). *Stakeholder Alignment for Community Design and Fabrication Capability: The U.S. Network of Fab Labs*. Paper presented at the ndustry Studies Association 2012 Annual Conference, Pittsburgh. Panel retrieved from

Berry, D. M. (2012). *Understanding Digital Humanities*. New York: Palgrave MacMillen.

BioCurious. (2013). BioCurious – your Bay Area hackerspace for biotech. Retrieved 12 February, 2013, from http://biocurious.org/

Blurb. (2013). Blurb Books. Retrieved 12 February, 2013, from http://www.blurb.com/

Caldwell, S. (2010, October 23). Fab Labs offer possible boon to rural villages, *Fairbanks Daily News-Miner*. Retrieved from http://www.newsminer.com/news/local_news/article_221958f8-ea53-5910-8fdc-3d70d38de9dc.html

Champaign Unit 4 School District. (2013). Stratton Elementary School. from http://www.champaignschools.org/schools/home/?id=12

Cheok, A. D., Kok, R. T., Tan, C., Fernando, O. N. N., Merritt, T., & Sen, J. Y. P. (2008). *Empathetic living media*. Paper presented at the Proceedings of the 7th ACM conference on Designing interactive systems, Cape Town, South Africa.

Craig, A. B. (2013). *Understanding Augmented Reality: Concepts and Applications (forthcoming)*. San Francisco: Morgan Kaufman.

CSDH/SCHN. (2013). Canadian Society for Digital Humanities / Société canadienne des humanités numériques (CSDH/SCHN). from http://csdh-schn.org/

CUCFL. (2011a). Advanced - Press Fit Box. Retrieved 12 February, 2013, from http://cucfablab.org/book/advanced-press-fit-box

CUCFL. (2011b). CUCFL Summer Sessions: 2011. Retrieved 12 February, 2013, from http://cucfablab.org/blog/cucfl-summer-sessions-2011

CUCFL. (2011c). Fab Off. Retrieved 12 February, 2013, from http://cucfablab.org/blog/fab

CUCFL. (2011d). Fab Off 2011, The Video. Retrieved 12 February, 2013, from http://cucfablab.org/blog/fab-2011-video

CUCFL. (2011e). Fab Off Slideshow! Retrieved 12 February, 2013, from http://cucfablab.org/blog/fab-slideshow

CUCFL. (2011f). First Blue Platter Saturday. Retrieved 12 February, 2013, from http://cucfablab.org/blog/first-blue-platter-saturday

CUCFL. (2012a). Fab Lab & iFoundry Workshop featuring Federico Joselevich, March 31, 2012. Retrieved 12 February, 2013, from http://cucfablab.org/image/fab-lab-ifoundry-workshop-featuring-federico-joselevich-march-31-2012

CUCFL. (2012b). Hack a t-shirt event - Must sign up by Friday April 13th. Retrieved 12 February, 2013, from http://cucfablab.org/blog/hack-t-shirt-event-must-sign-friday-april-13th

CUCFL. (2012c). Pen-on-Paper Flexible Electronics Workshop. Retrieved 12 February, 2013, from http://cucfablab.org/blog/pen-paper-flexible-electronics-workshop

CUCFL. (2013a). Champaign Urbana Community Fab Lab Retrieved 12 February, 2013, from http://cucfablab.org/

CUCFL. (2013b). CUC Fab Lab at the Public Engagement Symposium. Retrieved 1 March, 2013, from http://cucfablab.org/blog/cuc-fab-lab-public-engagement-symposium

CUCFL. (2013c). Example Crations. Retrieved 12 February, 2013, from http://cucfablab.org/book/example-creations

CUCFL. (2013d). Governance and Operations. Retrieved 12 February, 2013, from http://cucfablab.org/book/governance-and-operations

CUCFL. (2013e). Saturday Fablab for February. Retrieved 12 February, 2013, from http://cucfablab.org/blog/saturday-fablab-february

Cutcher-Gershenfeld, J., & Lawson, C. Valuing the Commons: A Fundamental Challenge across Complex Systems *ESD Working Paper Series - MIT Engineering Systems*. Cambridge: Massechusets Institute of Technology.

D'Errico, F., & Backwell, L. (Eds.). (2005). *From tools to symbols :from early hominids to modern humans*. Johannesburg: Witwatersrand University Press.

Davis, S. (1987). *Future Perfect*. Reading: Addison Wesley.

Doctorow, C. (2009). *Makers*. New York: Tor.

Don Moyer Boys and Girls Club. (2013). Don Moyer Boys and Girls Club (Champaign, Illinois). Retrieved 12 February, 2013, from http://www.dmbgc-cu.org/

Edwards, D. (2008). *Artscience: Creativity in the Post-Google Generation*. Cambridge: Harvard University Press.

Fab Academy. (2013). Fab Academy: Principles, applications and implications of digital fabrication. from http://www.fabacademy.org/

FabFolk. (2013). The International Fab Lab Association. Retrieved 12 February, 2013, from http://fablabinternational.org/

FabWiki. (2013). Labs. Retrieved 12 February, 2013, from http://wiki.fablab.is/wiki/Portal:Labs

Fluidforms. (2011). CASSIUS Punching Bag Design Interface. from http://vimeo.com/2847325

Fountain, H. (2013). Tools of Modern Gunmaking: Plastic and a 3-D Printer. *The New York Times*.

Frankowski, L. A. (1987). *Copernick's Rebellion*. New York: Ballantine Books.

gameful.org. (2012). Gameful. from http://gameful.org

Gauntlett, D. (2011). *Making is Connecting: The social meaning of creativity from DIY and knitting to YouTube and Web 2.0*. Cambridge: Polity.

Gershenfeld, N. (2005). *Fab: The Coming Revolution On Your Desktop-From Personal Computing to Personal Fabrication*. New York: Basic Books.

Ginger, J. (2013). Digital Literacy Resources for Emerging Maker Spaces: Draft for the Chicago Public Library Maker Space Café: Champaign Urbana Community Fab Lab.

Ginger, J., McGrath, R., Barrett, B., & McCreary, V. (2012). *Mini Labs: Building Capacity for Innovation Through A Local Community Fab Lab Network*. Paper presented at the World Fab Conference (Fab8), Wellington, NZ. http://cucfablab.org/sites/cucfablab.org/files/CUCFL F8 2012 Submission 08.14.2012.pdf

Gold, M. K. (Ed.). (2012). *Debates in the Digital Humanities*. Minneapolis: University of Minnesota Press.

HackerspaceWiki. (2013). hackerspaces. Retrieved 12 February, 2013, from http://hackerspaces.org/wiki/Hackerspaces

Haldeman, J. W. (1974). *The Forever War*. New York: St. Martin's Press.

HASTAC. (2013). Humanities, Arts, Science Advanced Collaboratory. Retrieved 12 Feburary, 2013, from http://hastac.org

Howard, J., & Howard, I. (2013, March 2). [Youth council information].

Illich, I. (1973). *Tools for Conviviality*. London: Fontana.

Institute of Museum and Library Services. (2012). MLS Awards $249,999 to the Chicago Public Library Foundation to Create a Maker Space. from http://www.imls.gov/imls_awards_249999_to_the_chicago_public_library_foundation_to_create_a_maker_space.aspx

Instructables. (2013). DIY BioPrinter. from http://www.instructables.com/id/DIY-BioPrinter

Johnson, J. (2010, Jan 26). Atoms Are Not Bits; Wired Is Not A Business Magazine. Retrieved 12 February, 2013, from http://gizmodo.com/5457461/atoms-are-not-bits-wired-is-not-a-business-magazine

Kelly, K. (2010). *What Technology Wants*. New York: Penguin Group.

Kreuger, M. W. (1991). *Artificial Reality II*: Addison-Wesley.

Kroski, E. (2013). A Librarian's Guide to Makerspaces: 16 Resources. from http://oedb.org/blogs/ilibrarian/2013/a-librarians-guide-to-makerspaces/

Lankshear, C., & Knobel, M. (2008). *Digital Literacies: Concepts, Policies and Practices*. New York: Peter Lang Press.

Latulipe, C., Wilson, D., Huskey, S., Word, M., Carroll, A., Carroll, E., . . . Lottridge, D. (2010). *Exploring the design space in technology-augmented dance*. Paper presented at the CHI '10 Extended Abstracts on Human Factors in Computing Systems, Atlanta, Georgia, USA.

Lessig, L. (2008). *Remix: Making Art and Commerce Thrive in the Hybrid Economy*. New York: The Penguin Press.

Levy, S. (2006). *The Perfect Thing: How the iPod Shuffles Commerce, Culture, and Coolness*. New York: Simon and Schuster.

Lulu Press. (2013). Self Publishing, Book Printing, and Publishing Online. Retrieved 12 February, 2013, from http://www.lulu.com/

Mack, E. (2013, February 12). Here's the 3D-printing institute in Obama's State of the Union. from http://news.cnet.com/8301-17938_105-57569093-1/heres-the-3d-printing-institute-in-obamas-state-of-the-union/

Make. (2011). Make: technology on your time. from http://makezine.com/

Makerbot Industries. (2013). Thingiverse. Retrieved 12 February, 2013, from http://www.thingiverse.com/

Makerspace Urbana. (2013). Makerspace Urbana. Retrieved 12 February, 2013, from http://makerspaceurbana.org/

Mazalek, A., Nitsche, M., Rebola, C., Wu, A., Clifton, P., Peer, F., & Drake, M. (2011). *Pictures at an exhibition: a physical/digital puppetry performance piece*. Paper presented at the Proceedings of the 8th ACM conference on Creativity and cognition, Atlanta, Georgia, USA.

McGonigal, J. (2011). *Reality is broken: why games make us better and how they can change the world*. New York: Penguin Press.

McGrath, R. (2012). Pteranodon Project Adapted from 'instructables.com' (includes plans). from http://cucfablab.org/blog/pteranodon-project-adapted-instructablescom-includes-plans

McGrath, R. E., Rischau, J., & Craig, A. B. (2012). Transforming Creativity: Personalized Manufacturing Meets Embodied Computing. *Knowledge Management and E-Learning, 4*(2), 157-173.

Morris, R. (2009). *The fundamentals of product design*: AVA Publishing SA.

Mota, C. (2011). *The Rise of Personal Fabrication*. Paper presented at the Creativity & Cognition, Atlanta.

Museum of Science and Industry, C. (2013). Wanger Family Gab Lab. from http://www.msichicago.org/whats-here/fab-lab/

New Media Collective. (2013). the pool. Retrieved 12 Feburary, 2013, from http://pool.newmedia.umaine.edu/

Norden. (2013). Norden Design. Retrieved 12 February, 2013, from http://www.norden-design.com/

Omaha Sprouts. (2013). City Sprouts: Grow with Us. from http://www.omahasprouts.org/demosite/

Open Source Hardware Association. (2013). Open Source Hardware Association. from http://www.oshwa.org/

PBWorks. (2012). Learn to Teach, Teach to Learn. from http://learn2teach.pbworks.com/w/page/15779288/Learn_2_Teach%2C_Teach_2_Learn

Pine, B. J. (1993). *Mass Cusomization: The New Frontier in Business Competition*. Boston: Harvard Business School Press.

Plotkin, R. (2009). *The Genie in the Machine*. Stanford: Stanford University Press.

Rehsteiner, F. H. (2003). Rapid Prototyping in Manufacturing. In A. Dashchenko (Ed.), *Manufacturing Technologies for Machines of the Future* (pp. 367-380). New York: Springer.

Renfrew, C., Frith, C. D., & Malafouris, L. (Eds.). (2009). *The sapient mind :archaeology meets neuroscience*. Oxford: Oxford University Press.

Rischau, J. (2011). *Custom Digital Fabrication in Industrial Design.* (MFA), University of Illinois, Urbana-Champaign, Urbana. Retrieved from http://hdl.handle.net/2142/26045

Schiphorst, T. (2009). Body Matters: The Palpability of Invisible Computing. *Leonardo, 42*(3), 225-230.

Schreibman, S., Siemens, R. G., & Unsworth, J. (Eds.). (2004). *A companion to digital humanities*. Malden, MA: Blackwell Pub.

Shapeways, I. (2013). shapeways. Retrieved 12 February, 2013, from http://www.shapeways.com/about/

Sherman, W. R., & Craig, A. B. (2003). *Understanding Virtual Reality: Interface Application and Design*. San Francisco: Morgan Kaufmann.

Shirky, C. (2010). *Cognitive Surplus: Creativity and Generosity in a Connected Age*. New York: The Penguin Press.

Smith, B. D. (2011). *Telematic Composition.* (Ph.D. Dissertation), University of Illinois, Urbana-Champaign, Urbana. Retrieved from http://hdl.handle.net/2142/29843

Smithsonion Institution. (2013). Early Stone Age Tools. from http://humanorigins.si.edu/evidence/behavior/tools/early-tools

Stephenson, N. (1995). *The Diamond Age, Or, Young Lady's Illustrated Primer*. New York: Bantam Books.

Street, B. V. (2005). Understanding and defining literacy: United Nations Educational, Scientific and Cultural Organization.

Stross, C. (2004). *Iron Sunrise*. New York: Ace Books.

Tap In. (2013). Tap In Leadership Academy. Retrieved 12 February, 2013, from http://new.tapinacademy.org/

The I-STEM Education Initiative. (2013). C-U Fab Lab Fosters Creativity in Local Youth. from http://www.istem.illinois.edu/news/fab_lab.html

The Product Manufactory. (2013). The Product Manufactory. Retrieved 12 February, 2013, from http://www.theproductmanufactory.com/

The South End Technology Center. (2013). The South End Technology Center. Retrieved 12 Feburary, 2013, from http://www.tech-center-enlightentcity.tv/

The Urbana Free Library. (2013a). Creation Technology at Your Library. Retrieved 12 February, 2013, from http://urbanafreelibrary.org/blogs/2013/02/25/creation-technology-your-library

The Urbana Free Library. (2013b). The Urbana Free Library. Retrieved 12 February, 2013, from http://urbanafreelibrary.org/

UNESCO. (2004). The Plurality of literacy and its Implications for Policies and Programme. Paris: United Nations Educational, Scientific and Cultural Organization.

Urbana-Champaign Mini Maker Faire (2012). Urbana-Champaign Mini Maker Faire. Retrieved 12 February, 2013, from http://ucmakerfaire.blogspot.com/

Watson, G. (2011). The Champaign-Urbana Community Fab Lab. *ACM interactions, 18*(5), 86-87.

Wohlsen, M. (2011). *Biopunk: DIY Scientists Hack the Software of Life*. New York: Penguin.

YouTube. (2013). YouTube. Retrieved 12 February, 2013, from http://www.youtube.com/