“Rapid Prototyping to Support Experimental History”

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Abstract

The idea of digitization is familiar to most scholars, but new technologies also allow us to turn bits back into atoms, through reverse processes of materialization. We show that affordable do-it-yourself 3D printers and open source hardware allow historians to manufacture artifacts, devices, exhibits and environments that can shape people’s experience of place, community and the past. As a case study we provide some specific examples from Elliott’s PhD work on the history of stage magic. More generally, we argue that emerging technologies allow historians to take a more playful, experimental and sensuous approach to research, teaching and learning.

At sites around the world, a growing community of self-identified makers, crafters, hackers, and DIY fabricators is in the process of taking on all of the hallmarks of a new social movement. According to Charles Tilly, a new social movement is characterized by the innovative synthesis of three things: a *campaign*, a *repertoire* of performances, and displays of *worthiness, unity, numbers* and *commitment*. Each of these is evident in the community of makers, widely construed.[1]

The campaign is probably best summed up by *MAKE* magazine: "we celebrate your right to tweak, hack, and bend any technology to your will." *MAKE* is published by O'Reilly Media, whose motto is "spreading the knowledge of technology innovators." In addition to *MAKE*, O'Reilly also publishes a popular series of books on hacking (e.g., Igoe's *Making Things Talk*), blogs and forums, and a do-it-yourself instruction website called *Instructables*.[2] Articles in *MAKE* profile prominent makers and hackers and provide step-by-step instruction in building projects at a variety of skill levels. The magazine also editorializes against things like the copy restriction of software and media and the confiscation of Swiss army knives and multi-tools in airports, and in favor of the open source ethos and of products that invite users "to look inside and see the moving parts... make repairs and improvements, and even harvest components once the product ceases to be useful."[3]

O'Reilly sponsors a national meeting (the Maker Faire) and provides publicity for local hacker/artist groups like Dorkbot, which meets in about 80 cities worldwide, including Vancouver, Toronto, Ottawa and Montreal.[4] In addition to real-world activities, community members are able to perform online in a variety of forums, including *Instructables*, rehearsing core values of sharing and openness, resourcefulness, a can-do attitude and a willingness to open the black box. If they wish, they can even buy t-shirts with slogans like "If you can't open it, you don't own it," "re-use, re-cycle, re-make," "hacking is not a crime!" and "Make: void your warranty, violate a user agreement, fry a circuit, blow a fuse, poke an eye out..."

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[1] Tilly 2004. Makers also constitute a "recursive public" in the sense of Kelty 2008.
[2] O'Reilly also published a companion magazine called *CRAFT*, now defunct.
[3] Dougherty 2005.
[4] Dorkbot also meets in Second Life.

When President Barack Obama celebrated "the risk-takers, the doers, the makers of things" in his 2009 inaugural address, O'Reilly immediately turned the phrase into a t-shirt.[5]

The maker community extends far outside the ambit of O'Reilly Media, of course, overlapping with many other interest groups. It includes a global network of *hackerspaces*, workshops operated by community members who wish to share ideas, tools, and techniques, and to work collaboratively on projects.[6] It includes efforts to crowdsource the production of everything from automobiles to prosthetics.[7] And, most relevant to the work we describe here, it includes groups of people dedicated to producing software (like the programming language *Processing*), hardware platforms (like *Arduino*), and computer-controlled machines that are able to print small three-dimensional objects (like *RepRap*).[8] We discuss all three of these technologies below. In each case, the designers and makers profess and ethic of *open source*, making plans, software, and construction details freely available online.[9]

The present conjuncture—of making as a new social movement, of easy-to-use and freely-available platforms that invite modification, of detailed online instructions for doing just about anything—makes it almost costless for historians and other humanists to research, teach, learn, play and experiment with new technologies. These include digital technologies, of course, the blogs, wikis, podcasts, games, and social media described by other contributors to this volume.[10]

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[5] "President Barack Obama's Inaugural Address," *The White House Blog* (21 January 2009). Available at <http://www.whitehouse.gov/blog/inaugural-address/> consulted 16 April 2010. For the t-shirt, see <http://blog.makezine.com/archive/2009/01/winner_make_the_risktakers_the_doer.html> consulted 16 April 2010.

[6] See <http://hackerspaces.org/wiki/> consulted 16 April 2010. Hackerspaces have already sprung up in many Canadian cities. See, for example, VHS in Vancouver <http://vancouver.hackspace.ca/doku.php>, THINK|HAUS in Hamilton <http://www.thinkhaus.org/>, Kwartzlab in Kitchener/Waterloo <http://kwartzlab.ca/>, or hacklab.to in Toronto <http://hacklab.to/>. All sites consulted 18 April 2010.

[7] For automobiles, see Local Motors <http://www.local-motors.com> consulted 16 April 2010, Anderson 2010 and Johnson 2010. For prosthetics, see The Open Prosthetics Project <http://openprosthetics.org> consulted 16 April 2010.

[8] See <http://processing.org>, <http://arduino.cc> and <http://reprap.org> respectively, consulted 16 April 2010.

[9] Weber 2005; Torrone 2007.

[10] [Include links to other chapters in the volume here.]

We argue that the time is right for humanists to play and experiment with technologies of material production, too.

Humanistic Fabrication

Manufacturers have been at the centre of innovation in material products for centuries, but the work of researchers such as Eric von Hippel suggests that the balance is shifting somewhat.[11] As the cost of computers and software has fallen, it has become possible for individuals to acquire the equipment necessary to design complicated artifacts and electronics using Computer-Aided Design (CAD) software, and to program simulations and test and measurement routines for prototypes. Some people are motivated to do this, because, as von Hippel notes, the only group that benefits *directly* from innovation are the *users* of a good or service. “All others (here lumped under the term 'manufacturers') must sell innovation-related products or services to users, indirectly or directly, in order to profit from innovations.”[12] There is thus a strong incentive for users to be able to innovate on their own behalf, and the result has been a gradual democratization of innovation as more and more users have become involved in improving the services and products that they rely on. Furthermore, von Hippel's work shows that communities of user-innovators are much more likely than manufacturers to give away information about their own developments, creating a public good.

In a number of fields of design, this transition has already occurred. The widespread availability of very inexpensive laser and photo printers, the incorporation of desktop publication features into word processing software, and the free availability of photographs, fonts and clip art make it possible for just about anyone with a modicum of equipment to produce a pamphlet, newsletter, poster or booklet that has the same high quality as the professional products of two decades ago. There are even online tutorials to teach the fundamentals of vector illustration, coloring, photographic manipulation, kerning, and so on. This is not to say that

[11] von Hippel 1976, 1988, 2005.
[12] von Hippel 2005: 3. Of course, the same logic suggests that humanists will be best served by software that they create for themselves. [Include links to other chapters in this volume.]

professional graphic design has disappeared, merely that professional designers must now distinguish themselves in a sea of amateurs. Digital cameras and sites like Flickr have changed the landscape of photography; digital video cameras, blogs and YouTube have changed journalism, and so on.

In the past few decades, the cost of commercial computer-controlled rapid prototyping and fabrication devices dropped precipitously. News articles from the early 1990s put the price of an entry-level commercial setup close to the million dollar mark. By the turn of the millennium, an equivalent system could be had for about a tenth as much. A company called Desktop Factory, established in 2004, is now taking orders for a 3D printer that will cost about $5,000, and kits for home-built fabricators like RepRap can each be purchased for much less.[13] Meanwhile, services like Shapeways provide low-cost on-demand 3D printing for individuals.[14] As with the earlier case of desktop publishing, this democratization of innovation will certainly not lead to the demise of professional industrial design and manufacturing, but it will open up the space of material fabrication and customization to the masses.[15]

Like some commercially-available 3D printers, the *RepRap* works by precisely positioning a tiny bead of molten plastic. If you've never seen one in action, imagine a robot wielding a tiny hot glue gun, building up a three dimensional object one layer at a time.[16] Unlike the commercial alternatives, however, the creators of RepRap are on a mission. The ultimate goal of these do-it-yourself manufacturers is to create a science-fiction-inspired *replicator*: a device that can make anything, including all of its own component parts. Many of them imagine a world far beyond the limitations of present-day technology, when people will have 'wealth without money.' When an appliance breaks, its owner will be able to scan the broken part and print a replacement. Whenever anyone needs something they

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[13] By comparison, the first widely available laser printer, the Apple LaserWriter, had a starting price around $7,000 in 1985. A MakerBot, a RepRap derivative kit, can now be purchased for US $750. See <http://makerbot.com> consulted 16 April 2010.
[14] See <http://www.desktopfactory.com> and <http://www.shapeways.com>, consulted 16 April 2010.
[15] Cf. the recent exchange between Anderson 2010 and Johnson 2010.
[16] [If we are going to have pictures or diagrams, one will save about a thousand words here.]

will be able to download free plans and print out a copy. When they are done with it, they will recycle the components to be used for something new. This imagined future is one of *cradle-to-cradle manufacturing*,[17] *mass customization*[18] and *democratized innovation*.[19] Some of the claims made on behalf of personal fabrication are pretty extreme; that the practice will, for example, "bring down global capitalism, start a second industrial revolution and save the environment."[20]

Although we suspect that none of those things will actually come to pass, RepRaps are fun to play with and good to think with, and they beg to be understood in historical context. Two such contexts come to mind immediately: the industrial revolution and the birth of the personal computer in the 1970s. Both developments were stimulated by a rapidly changing landscape of costs and opportunities. During the industrial revolution, an unprecedented ability to harness and concentrate energy led to the growth of capital-intensive factories. The revolution in personal computing was stimulated, in part, by the availability of inexpensive electronic modules in the form of integrated circuits. In both cases, amateurs played a very important role in innovation.[21] The information costs associated with innovation have also been very different at different times, and a historically nuanced understanding of manufacturing and innovation in the present moment will have to take these changes into account, particularly as humanists become makers themselves.[22]

We're interested in personal fabrication as historians, and we know that if we want to understand technical practices or material artifacts, we need to go beyond words to the things themselves.[23] This is imperative because there are good reasons for believing that much technical and scientific knowledge is tacit and

[17] McDonough & Braungart 2002.
[18] Kieran & Timberlake 2004.
[19] Gershenfeld 2000, 2005.
[20] Randerson 2006.
[21] For the industrial revolution, see, e.g., Wallace 1978, Uglow 2002, Jacob & Stewart 2004; for personal computers, Campbell-Kelly & Aspray 1996, Ceruzzi 2003, Turner 2006.
[22] Long 2001.
[23] Mahoney 1999.

embodied, and thus learned only with difficulty.[24] Peter Dear, writing about the technical tracts of the medieval and early modern periods, says:

> The historian William Eamon, in his studies of such literature, has characterized these 'technical recipe books' as a means whereby the 'veil of mystery' that had hitherto surrounded the practical crafts was lifted, so that ordinary people could see that the craftsman was not possessed of some arcane wisdom, but simply had knowledge of a set of techniques that, in principle, anyone could apply. This is not a notion that should be taken for granted, however. Studies in recent decades of the ways in which expert knowledge is constituted and passed on suggest that practitioners do indeed possess skills that are communicated only with difficulty. Their practical knowledge is often unlearnable from the eviscerated accounts that appear in the pages of experimental papers (in the sciences) or technical manuals (in skilled craftwork in general). Thus, if Eamon is right, the growing sense that developed during the sixteenth century, as a consequence of printing and its uses, that practical craft knowledge ('know how') can be reduced to straightforward rules of procedure that can be acquired readily from books, was to a large degree an illusion. If this is so, it is an illusion that we have inherited.[25]

Historians, for the most part, have tended to ignore this problem of learning tacit knowledge, and continue to concentrate on the representational sources with which they are most comfortable, even at the cost of being excluded from a crucial understanding of their subject matter.

Beyond understanding personal fabrication in historical context, we believe that it can play a central role in a new, experimental approach to the practice of history. In our work, we combine elements of traditional historical methodology with a reflexive pedagogical approach inspired by recent work in science and technology studies, and the hands-on, critical making that characterizes experimental archaeology. We follow Mody and Kaiser, who argue that pedagogy is a "central analytic category," not "merely as formalized classroom teaching techniques... but rather as the entire constellation of training exercises through which novices become working scientists and engineers." (From this perspective, pedagogy is central to our own development as humanists, too.) Participation in the

[24] Polanyi 1974.
[25] Dear 2001: 26-27.

reproduction of a community of practitioners holds out the hope of learning "broadly similar values, norms, and self understandings... not (or not only) in the abstract, but as enacted through daily interactions within specific settings."[26]

Towards Experimental History

A related path to tacit knowledge is through the critical, reflexive practices of making which characterize experimental archaeology.[27] As Coles noted in the early 1970s, many of the nineteenth-century founders of archaeology experimented with stone tools, reproducing artifacts as a way of understanding the conditions of their manufacture and use. Over time, the experimental method has become more widely used in the discipline, as researchers attempt to replicate earlier methods of growing crops, storing and preparing food, building houses, working with stone, wood, bone, antler, metals and other materials, and making paper, pottery and musical instruments. We might ask, where is the experimental history to match this practice in archaeology?

There have been precedents, of course, in both research and teaching.[28] Generations of intro physics students have followed in Galileo's footsteps by attempting to determine the law of motion using an inclined plane. Historians of science haven't always believed that Galileo performed the experiment that he reported, however. In the 1950s, Alexander Koyré described Galileo's experiments as "completely worthless," due to the "amazing and pitiful poverty of [his] experimental means." This view was subsequently challenged by Thomas Settle, who rebuilt the apparatus "essentially as Galileo described it," and recorded results in accordance with Galileo's. A further refinement was later provided by Stillman Drake. Historian of physics Robert Crease writes:

> By carefully studying a page of Galileo's notebook, Drake concluded that Galileo actually had arrived at the law using the inclined-plane method, but by marking out the time in a way that seems to have

[26] Mody & Kaiser 2008: 378.
[27] Coles 1973, Ingersoll, Yellen & Macdonald 1977, Miller 2007, Cunningham, Heeb & Paardekooper 2008.
[28] [The examples given here aren't intended to be comprehensive; they're ones that WJT was already familiar with. Suggestions welcome.]

> taken advantage of his strong musical training. As a competent lute player, Galileo could keep a beat precisely; a good musician could easily tap out a rhythm more accurately than any water timer could measure. Drake determined that Galileo had set frets into the track of the inclined plane—moveable gut strings of the kind used on early string instruments. When a ball was rolled down the track and passed over a fret, he would hear a slight clicking noise. Galileo, in Drake's speculative reconstruction, then adjusted the frets so that a ball released at the top struck the frets in a regular tempo—which for the typical song of the day was just over half a second per beat. Once Galileo had marked out fairly exact time intervals, thanks to his musical ear, all he would have to do would be to measure the distances between frets.[29]

This kind of practice can be brought into the classroom. At MIT, Jed Buchwald and Louis Bucciarelli offered a "historic experimentation" course where students did a close reading of primary sources from the history of physics, then attempted to reconstruct the apparatus described and to replicate the reported results.[30] For a number of years, Anne McCants has been working with various colleagues to offer hands-on courses on subjects like ancient and medieval cooking, and spinning and weaving fabrics.[31] Outside the academy, crafters and re-enactors make chainmail,[32] fire matchlock muskets,[33] grow heirloom vegetables,[34] take daguerreotypes,[35] and engage with the material past in an almost unimaginable variety of other ways.[36]

[We plan to extend our discussion of experimentation here in a number of directions. In particular, we intend to engage with questions of replication, Walter Benjamin's *aura*, the categories of 'natural experiment' and 'thought experiment', and the idea of fakes and forgeries.[37]]

[29] Crease 2003: 50-51.
[30] Buchwald & Bucciarelli 1999.
[31] e.g., McCants & Collett 2010; McCants, Collett & Knutson 2010.
[32] See <http://www.wikihow.com/Make-Chainmail> consulted 18 April 2010.
[33] See <http://www.youtube.com/watch?v=2KTS8PQ06Qo> consulted 18 April 2010.
[34] See <http://www.seedsavers.org/> consulted 18 April 2010.
[35] See <http://www.daguerre.org/> consulted 18 April 2010.
[36] de Groot 2008.
[37] [Link to work of Mills Kelly and other contributors here.]

Barbie and Ken Play Penn and Teller

[The bulk of our paper will consist of an extended case study of the experimental method in history, drawn from work that we are doing together this summer. We plan to recreate a number of stage magic illusions at model scale (hence the title of this section.) These models will serve as demonstration devices, have a playful, toy-like quality, and be pedagogically comparable to various kinds of other model-scale teaching tools, like scale mechanisms or crime scene dioramas.[38] Here are a few of the research questions that we are working with:

- What design decisions are due to the constraints of particular media? How can we use the material culture perspective to read the production of various artifacts, including antique originals, modern replicas, cheap plastic knockoffs?
- What new variations can we devise? How do these relate to the modern practices of stage magic? How does the possibility of mass customization change the art of illusion?
- What does the repeatability of a particular illusion or effect tell us about the history of sensation or perception?
- How does our own engagement with fabrication change our experience of what is methodologically possible?

In this section, we will also discuss the technologies that make it possible to create model-scale objects with embedded computation: the Processing programming language, the Arduino microcontroller, electronic transducers and actuators, and open source sharing of plans for hardware at sites like Thingiverse and Instructables.]

[38] For mechanical scale models see the Kinematic Models for Design Digital Library <http://kmoddl.library.cornell.edu/> consulted 19 April 2010; for crime scene dioramas, see Botz 2004, Mauriello & Darby 2004.

Spaces for Making and Playing

It is a sad fact that, in North America at least, most of the spaces available for graduate teaching and learning in the humanities are less suitable for hands-on making and experimenting than just about any kindergarten classroom in the country. We know that this kind of activity is crucial for child development, but is there any evidence it is less crucial for people in other age groups? John Dewey, Jane Addams, Bauhaus, the Foxfire project… this isn't something new, it's something we seem condemned to repeat.

[In this section we plan to situate our case study in our wider practice as teachers and students. Some things to be covered:

- The idea of a 'history appliance,' imaginative engagement with a sensuous past, artifacts and environments as a way of communicating tacit knowledge and historical consciousness
- Classroom practices and projects (e.g., the model of Sputnik, a robot that recreates historic plays on a table-top hockey game, a wearable museum exhibit)
- Interactive museum exhibits. In our graduate course, students learn to create 3D representations in various ways (laser and touch probe scanning, drafting with CAD, etc.) and then to materialize those, either through 3D printing or subtractive machining. These digital and physical objects are then used in conjunction with electronics and computers to make museum exhibits that have interactive, tangible or ambient components.
- Mechanical understanding. By printing out models of nineteenth- and early twentieth-century gear trains and linkages, we can gain tangible insight into the mechanical technologies of earlier eras, many of which are now being put to new uses by DIY fabricators. It is one thing to look at an engraving of a pair of square gears, for example, but quite another to be able to print out a pair to experiment with.
- Community workshops like *Hacking as a Way of Knowing* (with Kee, Rockwell) and the *Wearables and E-textiles* workshop (with Nowviskie)

- Amateur / citizen science. Inexpensive 3D printing makes it easy to create custom objects in workshop settings. In conjunction with analog sensors and open source hardware platforms like Arduino, it is easy to create low cost environmental sensors of various sorts, allowing interested citizens to monitor and share data about climate, pollution, etc.
- Digitizing and hacking smells (Strlič et al 2009, Holder 2008)
- Haptic interfaces to material objects]

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