UNPACKING THE OPPORTUNITIES AND CHALLENGES OF SHARING 3D DIGITAL DESIGNS: IMPLICATIONS FOR IP AND BEYOND

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UNPACKING THE OPPORTUNITIES AND CHALLENGES OF SHARING DIGITAL DESIGNS AMONG 3D PRINTING USERS: IMPLICATIONS FOR IP AND BEYOND

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This doctoral research identifies and examines the challenges that 3D printing users face in creating and sharing digital design files, hardware and documentation related to intellectual property and other critical issues. In particular, this thesis describes the processes that 3D printing users undertake in leveraging Creative Commons (CC) and other approaches to securing IP rights. To investigate these questions, I employ a theoretical lens informed by the social construction of technology, free innovation and recursive publics. Through a combination of 20 open-ended interviews with members of the 3D printing community, the development of three in-depth case studies and additional secondary data analyses, I find that fewer members of the community use Creative Commons than originally expected and that there are persistent gaps in the understanding of how Creative Commons can be useful for the sharing of digital design files, hardware and documentation.

While the original goals of this research focused more specifically on the IP issues facing 3D printing users, the overall findings of these activities provide broader insights around how users of a particular technology, in this case 3D printing, engage in different kinds of practices around sharing what they have created and the ways that

these behaviors create an active community committed to perpetuating the creation of new knowledge, solutions and objects. While this research started out with very focused questions about one very specific kind of sharing (the use of CC licenses, what drives this use, challenges around this use, etc.), the research and findings ended up being more about how the broader practices of sharing digital design files are informed by the existing values and experiences of the individuals involved, field-specific issues and existing power structures, institutions and hierarchies that can enable or challenge this kind of work.

Collectively, this research suggests that while IP issues do create barriers to 3D printing users sharing the digital design files that they have created, many 3D printing users have found different ways to address these issues. The learning and insights from this research are used to develop a set of recommendations to inform the development of technical mechanisms, educational initiatives and policy interventions that make it possible for 3D printing users to continue to share what they've created in ways that encourage open innovation and the building off on each other's work safely, securely and with the acknowledgement of creators' contributions.

BIOGRAPHICAL SKETCH

Stephanie Santoso is a PhD Candidate in Information Science. She is the Director of Maker Initiatives at the education non-profit organization, Citizen Schools. She has worked as the Senior Advisor for Making at the White House Office of Science and Technology Policy during the Obama Administration and has served as a Program Fellow at the Gordon and Betty Moore Foundation and Infosys Foundation USA. She is also a Founding Board Member of the national non-profit organization, Nation of Makers. She holds an MS in Information Management from Syracuse University and a Bachelor of Science in Marketing and Media Studies from the University of Virginia.

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LIST OF ABBREVIATIONS

3D	three dimensional
AR	augmented reality
CC	Creative Commons
DMCA	Digital Millennium Copyright Act
FDM	fuse deposition modeling
GLAM	galleries, libraries, archives, museums
IP	intellectual property
SCOT	social construction of technology
SLA	stereolithography
SLS	selective laser sintering
USPTO	US Patent and Trademark Office
VR	virtual reality

1 CHAPTER 1- Introduction

3D printing is a technology that was developed in the late 1980s and 1990s, with the patents to the technology being held by just a couple of companies and used primarily for industrial applications such as in engineering and architecture. This technology provided organizations with the ability to design and manufacture highly specialized and customized parts, objects and structures more quickly and more cost effectively than existing methods. Critical to 3D printing was the ability to digitally model the desired object, making it possible to change what a 3D printer produces without the complexities of changing molds or tooling. Even today, 3D printing or additive manufacturing is best used for the production of small batches of an object, compared with forms of traditional manufacturing where scalability to large volumes is an advantage. While often referred to as one technology, 3D printing is a technology category, which includes different 3D printing techniques that vary by material and process. This includes stereolithography (SLA), selective laser sintering (SLS) and fuse deposition modeling (FDM) (Lipson & Kurman, 2013). Today FDM is the most common type of 3D printing among individual consumers. In its early years, industrial 3D printers could cost upwards of $50,000. Today 3D printing has a much wider variety of applications ranging from health and medical devices and automobiles to fashion and education compared to its use 30 years ago. Wohlers & Associates, a leading expert in 3D printing projected that the market for 3D printing, also known as additive manufacturing, will grow to $35.6 billion by 2024 (McCue, 2018). 3D printing continues to revolutionize how people can design and make things because it can be used to easily and cheaply customize projects; is a cost efficient way to rapidly prototype ideas; increases the speed with which individuals can bring products and solutions to market; has the capabilities to produce highly complex, intricate and geometric object designs; is one of several technologies enabling “desktop manufacturing” and is lowering the cost of previously expensive devices.

One main reason for the democratization and increasing ubiquity of 3D printing has been the expiration of key patents associated with 3D printing, prompting the development of open source 3D printing projects and related initiatives which have broadened accessibility to the technology. After key patents for FDM 3D printing expired in the early 2000s, the RepRap project was launched in the UK with the goal of creating a low cost 3D printer that could print its own components (“RepRap project,” 2019). This project formed the basis for many of the 3D printers that are currently on the market today which use heated plastic filament to create objects. At the time of this writing, there are more than 800 projects on Kickstarter related to 3D printing and an individual can purchase a 3D printer for $99 USD (Kickstarter, 2019). While there are now low-cost 3D printers, there is significant variation with regards to the technical capabilities between lower end printers and their industrial counterparts. Over the past 10 years, subsequent patents have also expired related to SLA and SLS, making it possible for individuals to produce objects with different structural qualities, out of hard and soft materials (metal, plastic, ceramic, etc.) and at higher resolutions.

The expanded use of 3D printers is also due to the developments of software and online platforms which make it easier for individuals with no previous experience with 3D modeling to leverage the technology (All3DP, 2019; Griffey, 2014). Free or low-cost and easier to use software such as Tinkercad, Sketchup and Morphi have created pathways for non-technical and younger users to create digital designs of their ideas, projects and products (Griffey, 2014).

Individuals and organizations can upload and share 3D models for others to download, modify and use through online repositories like Thingiverse and GrabCAD. These developments have lowered the learning curve for using 3D printing. As of this writing, there are more than 1.1 million digital design files available for download on Thingiverse (“Thingiverse About,” 2019).

1.1 Research Problem

As 3D printing becomes more accessible with more individuals using the technology across different fields and applications, policy and regulation issues for 3D printing continue to emerge. These issues involve both the technology of the printer and the digital object designs that are needed in order to produce the 3D printed objects. Intellectual property is one of the most pressing policy issues currently facing 3D printing. The IP issues break down into two different areas 1) the patent and copyright issues related to the technology of the 3D printer itself; 2) copyright, patent and trademark issues related to the digital design files (Weinberg, 2010). Many experts have articulated that the technology did not spread to other fields and applications for the better half of 20 years because key patents were held by only several companies (Lipson & Kurman, 2013; Wohlers & Gornet, 2014). The expiration of patents resulted in the development of new 3D printer manufacturing startups, but there is still concern that larger companies are continuing to file overly broad design and process patents which could limit the development of the technology moving forward.

The copyright, patent and trademark issues related to the digital object design files was originally the main focus of this dissertation research. A digital design file is necessary for the 3D printing of any object. As the number of 3D printing users has grown over the years and the volume of digital design files shared online has exploded, a number of significant questions have emerged with regards to the extent to which the current IP system and framework can appropriately moderate the use of digital design files. My earlier research explored questions around whether digital design files would be subject to patent or copyright law and it was determined that similar to "architectural plans, models or drawings," it would seem logical that digital files for 3D objects would receive similar copyright safeguards (S. M. Santoso & Wicker, 2016). The point here was not that all IP issues related to digital design files would solely fall under copyright, but that the majority of these cases would be argued on the basis of copyright. This assessment is consistent with the way in which the community of 3D printing users have actively used Creative Commons licensing to share the digital design files they've created while seeking attribution/credit and managing how other users can utilize their files (S. M. Santoso & Wicker, 2016).

However, during a multi-stakeholder workshop (in which I participated) that was convened by Creative Commons in June 2016, one significant observation that was made and further discussed was that way in which a substantial portion of 3D printing users who leverage CC licenses to share their work online may not fully understand what the licenses cover and in some cases are using the licenses incorrectly (Park, 2016). This was just one of several significant issues that were identified as challenges that have emerged around the 3D printing community leveraging CC licenses. This group of individuals included representatives from 3D printing manufacturers, legal and policy experts focused on 3D printing, platforms where 3D digital files are shared online and leaders within the 3D printing community.

The convening hosted by Creative Commons led to the identification of three key pain points that need to be further explored:

- Attribution- Creative Commons licenses are being used to enable attribution to original creators, however there is no current way to ensure that this attribution carries over when a file is modified and re-posted (provenance).
- Blanket Use of Creative Commons- Licenses are being used to protect digital design files which may not be protectable by Creative Commons because the object is utilitarian, or portions of the object are utilitarian.
- Misuse of a Digital Design File- There is no current method for a creator being able to track how his/her file is used once it is posted to determine whether other users are leveraging the file according to the specified Creative Commons license.

A more detailed overview of these issues was summarized in a post-meeting write up by Creative Commons (Park, 2016). To date, there has not yet been in depth research conducted on the use of Creative Commons among the 3D printing community. A large proportion of 3D printing users currently leverage some type of Creative Commons licensing when they make their digital design files available online through platforms like Thingiverse. Light survey research conducted by MakerBot (the company which owns Thingiverse) in 2016 found that the majority of Thingiverse users use Creative Commons, but that these licenses and the current framework don't completely address the needs of 3D printing users (MakerBot, 2015a, 2015b).

Thus, the research problem that this dissertation intends to focus on is the need to gain a deeper understanding around the motivations of 3D printing users for using Creative Commons licenses, the challenges that they face in this process and existing needs surrounding the sharing of one's digital designs that are currently not being met. These findings and insights will be critical to informing the development of a platform or system with the technical features and policy mechanisms to ensure that 3D printing users fully understand what their options are when it comes to moderating the use of their digital design files and ensuring attribution.

Based on earlier research conducted by myself and other researchers, there is evidence which suggests that Creative Commons (CC) licenses are a main mechanism that 3D printing users leverage so that they can share what they have created with the broader community, allowing them to use this content under a certain set of specified conditions (Park, 2016; S. M. Santoso & Wicker, 2016). This research will explore some of these initial findings in greater detail by asking critical questions that investigate how 3D printing users make decisions about whether to use CC licenses, alternative approaches users take when they do not use CC licenses to share their work and an investigation of the significant factors and conditions that affect whether a user decides to share or not share digital design files. It is likely that some of these factors will be specific to the application of 3D printing.

There are also two related phenomena in 3D printing that must be examined in parallel because they have a direct impact on the ways in which individuals share their digital designs. First, is the way in which 3D printing as a technology has developed and evolved as the result of new groups having the opportunity to participate in the design and co-construction of the technology and the development of its applications. Second is the application of 3D printing across more sectors and industries, which has created new tensions, a number of which appear difficult to address and resolve through the existing IP legal infrastructure.

1.2 Research Questions

While the overarching findings from my research extended beyond issues related to the IP issues dealt with by 3D printing users, the original focus of my dissertation research was to examine in-depth, the landscape of Creative Commons use among the 3D printing community. The aim of this research was to make significant contributions to the development of a Creative Commons platform and metadata standard for 3D printing that would address several unique issues faced by 3D printing users in leveraging the existing set of Creative Commons licensing. Using a combination of in person and phone interviews and secondary research, my dissertation focuses on the following topics: 1) motivations for using Creative Commons; 2) level of understanding about Creative Commons and how the licenses function in relation to 3D digital designs; 3) challenges to using Creative Commons. Understanding the motivations for Creative Commons is multi-dimensional. One side of this involves the pure practicality of a user being able to specify how a digital design file is used. The other dimension focuses on the way in which Creative Commons is a way of signaling your values and identity to the broader community.

The key research questions are:

- Why do 3D printing users choose to use Creative Commons for their digital design files?
- To what extent do 3D printing users understand Creative Commons, how licenses can be used and what they provide?
- What challenges do 3D printing users have when it comes to using Creative Commons for digital design files?

- What technical mechanisms and other features could be used to address these challenges?

1.3 Goals of this Research

This research seeks to gain a deeper, nuanced understanding of the process that 3D printing users take in leveraging Creative Commons as part of their process for sharing digital design files. Digital design files, which are necessary for creating 3D printed objects are incredibly valuable because they provide an individual who possesses such a file with the data and code for producing any number of tangible, useful objects, ranging from specialized parts for machines, prosthetics and models for cutting edge scientific research. This research aims to further identify and examine the existing IP challenges that 3D printing users continue to face specific to digital designs, in an effort to develop solutions that could address these issues moving forward. The learnings and insights from this research will be used to develop a set of recommendations to help inform the development of technical and policy interventions that make it possible for 3D printing users to continue to share what they've created in ways that continue to encourage open innovation and the building off of each other's work safely, securely and with the acknowledgement of creators' contributions.

Over the course of the life of a technology there are critical points that can determine the trajectory of a technology- who uses it, what it is used for and how the technology is regulated by governments, industries and other institutions. This has been the case for every technology ranging from the printing press to the Internet. The approach of this research is to both examine the unique issues and tensions related to 3D printing as a technology while recognizing that many of these questions around use, sharing and IP recall those that were faced by technologies that have come before it and will likely affect those that come after 3D printing. In this respect, there will be a subset of learnings and recommendations from this research that could be relevant and applicable to the evolution of other technologies within society.

1.4 Relevance of this research

Gaining a deeper understanding of the impact of 3D printing across social, intellectual property and economic dimensions will provide insights that can lead to the development of mechanisms to resolve tensions and ensure that the potential for future technological innovation is maintained by providing individuals with the opportunity to use, hack, experiment and build upon the technology in question and future technologies, while balancing the need to provide creators with the appropriate recognition and compensation.

As 3D printing has increasingly become ubiquitous, 3D printing users are leveraging Creative Commons as a means of negotiating with the tensions around intellectual property they face. Creative Commons provides creators with the ability to share their content through a series of licenses that indicate how others can use their content. Creative Commons licenses work in conjunction with the traditional copyright system but allow users to offer certain usage rights to the public while reserving other rights, allowing creators more nuanced ways to share what they've created so that others can build upon it (Creative Commons, 2018, 2019). Beyond the licenses and tools that it has developed, Creative Commons has become a global community of individuals based on building "a more equitable, accessible, and innovative world" (Creative Commons, 2019).

It is important to specifically examine the ways in which 3D printing pushes the boundaries of the current U.S. intellectual property infrastructure because these laws, policies and values have historically played a significant role in the development of technological artifacts. IP infrastructure for the purposes of this research includes the traditional legal infrastructure (patents, copyrights, trademarks), alternatives to the traditional mechanisms (Creative Commons) and relevant movements such as the open source and maker movements. Different aspects of the IP infrastructure are informed by different sets of values, some of which align with one another and others which create tension or can be at odds with each other (i.e. maximizing commercial viability and broadening access).

Understanding the ways in which the existing IP infrastructure is affecting the use of 3D printing and how individuals are using this infrastructure to push the boundaries of co-construction of the technology allows one to gain insights into whether technological innovation is being limited or fostered by such policies, practices and mechanisms. Copyright and Creative Commons in particular have been a central part of the discussion and debate around what individuals can 3D print, how they can use 3D printers and who might be liable when something goes wrong. The design of spare parts for appliances, the creation of digital design files featuring trademarked content and the development of low-cost prosthetics are all examples of how 3D printing is upending the current IP infrastructure and the existing power structures of other technologies.

By understanding why 3D printing users choose to use Creative Commons, the challenges that users have in using Creative Commons and considering the other technical mechanisms and features that could be used to address these challenges beyond Creative Commons, I hope to inform the creation of an infrastructure that allows users to share their knowledge in a way that addresses the nuances of this particular technology and aligns with the norms, behaviors and values of the community of individuals that are using 3D printing. This research aims to understand how 3D printing users are sharing the works that they've created with the broader 3D printing community, the mechanisms, tools and platforms that they leverage when they decide to share their creations as well as the process that they undergo when deciding not to more openly share what they've created. While one can observe that the 3D printing community is leveraging Creative Commons licenses to share their creations, little research has been done to more deeply understand motivations for use, the decision making process for utilizing or not using CC and the social, technical and other challenges faced in using existing tools. Addressing these questions will help us gain deeper insights into what technical and policy interventions could be developed to address issues that are critical to fostering the sharing of knowledge and cultivating the development of the technology.

2 CHAPTER 2- Literature Review

2.1 Intellectual Property Rights Regimes and Creative Commons

To understand various ways 3D printing and its applications create tensions, questions and challenges to the current intellectual property infrastructure, we must understand U.S. copyright and patent law and how Creative Commons is structured to interact with the IP regulations developed by the government.

The World Intellectual Property Organization (2018) defines IP as creations of the mind, which include inventions, scientific discoveries, industrial designs, names, images, and literary and artistic works (WIPO, 2019). IP law is designed to ensure that creators receive the credit and compensation that they deserve for producing their works. By protecting their creations, IP law provides incentives for individuals to continue creating. In the United States, IP laws have gradually expanded to cover many more types of works while lengthening the terms of protection and placing tighter restrictions on fair use (U.S. Copyright Office, 2019). The expansion of IP law will undoubtedly benefit creators, but has an inverse effect on the knowledge, information, and content available to be freely used by the public.

2.2 Patent Law

When the U.S. Constitution was ratified in 1789, it provided a starting framework for how the federal government should be organized, how future laws and regulations would be developed and established the kinds of activities that Congress should concern itself with in dealing with the development of the United States as a country and the welfare of its people. At this very early milestone in the formation of the country, science, technology and the creation of new works were already identified as priorities for the nation, articulating that Congress would have the power "To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries" ("U.S. Constitution, Article I, Section 8, Clause 8," 2013, p. 8). For the leaders of the nation, innovation was integral to the creation of new knowledge- knowledge that was seen as necessary to building a thriving country.

One of the earliest debates about the government's role in science emerged as the Patent Act of 1790 was developed. The question was whether science could be patented and, in the end, to prevent patent law from being overly exclusive, it was determined that patents could not be granted to the scientific principles or ideas underlying a particular invention, but only the device itself. The act articulated that individuals could submit an application to receive a patent for "any useful art, manufacture, engine, machine, or device, or any improvement therein not before known or used" which would provide the inventor with the "sole and exclusive right and liberty of making, constructing, using and vending to others to be used" for a period of fourteen years (Patent Act, 1790). Thus, the federal government recognized the value of incentivizing individuals who sought to develop inventions with practical applications but determined that the scientific discoveries in and of themselves should be left alone. By choosing to make pure science (removed from application) as widely accessible as possible, Congress took an active stance that the tradeoff of compensating an individual for a discovery was not worth the potential loss of additional inventions, discoveries and solutions that could result from this science.

The US Patent and Trademark Office (USPTO) defines a patent as an intellectual property right granted by the Government of the United States of America to an inventor to exclude others from making, using, offering for sale, or selling the invention throughout the United States or importing the invention into the United States for a limited time in exchange for public disclosure of the invention when the patent is granted (U.S. Patent and Trademark Office, 2019). Utility patents protect the functionality of an invention, while design patents are those that protect the appearance of a product. It is often the case that inventions and their embodiments are protected by both utility and design patents. Since the initial introduction of the patent in 1790, numerous changes have been made to patent law in the U.S. This includes the shift in the valid length of time for a patent, which is 20 years for patents filed on or after June 8, 1995. An additional significant change in patents was ushered in with the 2011 Leahy-Smith America Invents Act, which shifts the U.S. patent system from “first to invent” to “first to file” (Leahy-Smith America Invents Act, 2011).

2.2.1 Patents and 3D Printing

The initial patents for 3D printing were held by a handful of companies that some critics argued limited the innovation and adoption of the technology. Other experts argued that while patents may have hindered others from commercially selling 3D printers, these patents have still stimulated innovation by forcing the development of creative workarounds (Kurman & Lipson, 2013). Over the past 10 years, key 3D printing patents have expired.

The expiration of these patents has had several different effects on the development of this technological artifact. First, a large number of consumer 3D printers leveraging fuse-deposition modeling (FDM), selective laser sintering (SLS) and stereolithograpy (SLA) techniques have entered the market. In some cases, these 3D printing companies have developed fully or partially open-source hardware and software, enabling individuals to build their own 3D printers while maintaining a commercial enterprise by selling fully assembled 3D printers or kits that contain all the necessary parts. Lulzbot, Prusa, Ultimaker and BCN3D are examples of companies that offer open source 3D printers and have in various ways, developed communities around their open source technologies which enable them to crowdsource valuable feedback and ideas from users, in some cases, co-designing improvements, new features and reiterating on current 3D printer models (Flynt, 2018). Second, a wider range of industries are actively using, experimenting and innovating with additive manufacturing than ever before. In healthcare and medicine, 3D printing is being used to produce low-cost prosthetics and medical devices and the technique is being used for bioprinting, to create tissue, cartilage composed body parts such as ears and, in the future, potentially organs. In architecture, large-scale 3D printing is being used to rapidly and effectively create buildings and structures, which could be useful in situations like natural disasters where people are displaced from their homes (Peters, 2018). Third, while older patents for 3D printing have expired, new patents related to the technology continue to be filed and issued. A study published in 2017 by IFI Claims Patent Services found that in 2017 over 320,000 3D printing patents were granted – an increase of 5.2% compared to the previous year. The report draws from over 70 sources of data and examined 320,003 Utility Grant patents by the USPTO. From 2013-2017, the compound annual growth rate for patents classified under "B33Y Additive Manufacturing" was 35%. For comparison, the only technology with a higher 5-year growth rate was e-Cigarettes at 45%. Machine Learning came in third at 34% (Petch, 2018). Of the additive manufacturing patents examined in this study, the top three companies which filed the most patents were General Electric, Xerox, Boeing and Desktop Metal respectively. Only Desktop Metal is a 3D printing manufacturer, while the other companies are in industries which have been increasingly utilizing 3D printing. In addition, Desktop Metal is a relatively new company, having been established in 2015 (Desktop Metal, 2019). This suggests that a shift is taking place- utility patents for 3D printing are no longer only mainly held by industrial 3D printing manufacturers, as they were in the 1980s and 1990s. As the applications for the technology continues to grow, companies, ranging from start-ups to multinational corporations are actively developing the technology to leverage within their sector or area of business, developing patentable intellectual property in the process.

As 3D printing has evolved, legal patent battles have also drawn in other related stakeholders, such as crowdfunding platforms like Kickstarter or Indiegogo, which are enabling a large number of 3D printing start-ups to crowdfund for the development of their products. In November 2012, 3D Systems filed a patent lawsuit against Formlabs, a 3D printing start-up that gained popularity and support by raising funds on Kickstarter. 3D Systems claimed that Formlabs had violated one of its stereolithography patents (Giseburt, 2012). In addition, 3D Systems also sued Kickstarter, arguing that because the platform took a percentage of the pledges made to Formlabs, it too had contributed to the damage caused to 3D Systems via patent infringement. 3D Systems also alleged that Kickstarter had violated its own Terms of Use by hosting a project that it should have known was in violation of an existing patent (*3D Systems Inc. V Formlabs Inc.*, 2012). After a two-year battle, 3D Systems and Formlabs settled the lawsuit, agreeing to dismiss all claims and counterclaims and for each side to pay its own legal costs. Additionally, Formlabs would pay 3D Systems an 8% royalty on Formlabs sales (Weinberg, 2014). This is just one example of the patent lawsuits between the “old guard” (industrial 3D printing manufacturers who held the initial patents issued in the 1980s and 1990s) and the “new guard” (start-up companies who have developed lower cost, desktop printers for consumers) that have emerged over the last 5-7 years.

In 2014, DSM, a company which manufactures photosynthetic polymers which can be used as printing material for stereolithography 3D printing filed an anti-trust lawsuit against 3D Systems, one of the largest manufacturers of stereolithography (SLA) 3D printers in the U.S. (*Desotech Inc. V. 3D Systems Corp*, 2014). DSM claimed that as a result of the design and implementation of a DRM mechanism for 3D Systems’ printers (an RFID tag in the printer communicates with a transmitter on the cap of a 3D Systems’ resin bottle), DSM suffered significant revenue loss because their materials could not be used for 3D Systems printers. According to DSM, this was anti-competitive behavior because there were only a few companies specializing in selling stereolithography 3D printers and 3D Systems held such a significant share of the SLA market. (*Desotech Inc. V. 3D Systems Corp,* 2014; IDTechEx, 2014; Krassenstein, 2014). However, the District Court in Northern Illinois ruled in favor of 3D Systems, articulating that stereolithography should not be considered a market or sub-market, but that the whole market for 3D printers is what should be taken into consideration here. The court neglected to make the distinction that different 3D printing techniques in many instances, are used for very specific purposes and that not all 3D printers are interchangeable. Stereolithography is often used for extremely high-resolution printing and the printing of intricate designs. A user with such needs is not likely to consider using a fused-deposition-modeling (FDM) desktop printer for this purpose.

2.2.2 Patents and 3D Printed Objects

Patents often protect functional or utilitarian items, such as spare parts for appliances and accessories for devices such as tablets, phones, and other mobile devices. Patent protection does not include exceptions for fair use like copyright, which means that the replication of a patented object for any use is not permitted unless authorized by the patent holder. Given that digital object designs are widely shared online by members of the 3D printing community, one crucial question that arises is who might be held liable for the 3D printing and distribution of a patented object? This has been debated by legal scholars and technical experts.

Holbrook and Osborn have explored the ways the patent system can protect patent owners against the appropriation of their inventions through digital design files. Through their analysis, they determine that indirect infringement documents would not provide enough grounding to protect patent holders from users developing digital designs of patented objects or devices. They articulate that the sales of digital design files could be considered direct patent infringement because of the way in which the economic value of the patented object is being leveraged for the commercial sale of the digital design file (Holbrook & Osborn, 2015). Hornick discusses how 3D printing has the potential to make IP rights irrelevant. He examines how the nature of the technology, its functionality and use make it difficult to identify IP infringement and enforce IP rights. To protect products, some companies such as Nike and Gillette have leveraged process patents, adopting a “product-by-process” claiming strategy (John Hornick, 2015). Hornick also explores the ways in which the development of non-IP rights based business models may provide companies an effective way to address the eroding commercial value of IP as 3D printing becomes more pervasive. Desai and Magliocca outline the patent and copyright concerns that will continue to emerge as 3D printing becomes more pervasive, recommending that Congress should think about an infringement exemption for home 3D printing and expanding takedown notice rules from the Digital Millennium Copyright Act to sites that host 3D digital designs (Desai & Magliocca, 2013).

2.2.3 Where 3D Models Intersect Patent Law

A user who creates the digital object design for the patented spare part of a washing machine could be held liable for direct infringement upon printing out the part (Doherty, 2012). If the digital object design file is uploaded and made available for free online, the online repository where it resides could be held liable for induced infringement if it could be proven that the site knowingly aided another individual in committing infringement. However, several other threshold requirements would need to be met before a basis for induced infringement could be formed, including proof of an act of direct infringement ("35 U.S. Code § 271—Infringement of patent," 1952).

Alternatively, if the digital object design was uploaded to a 3D printing marketplace so that the printed spare parts could be sold to others, the printing service could be accused of contributory infringement because it facilitated the unauthorized sale of a patented object. Again, the provisions of contributory infringement in patent law require additional conditions to be met before contributory infringement can be confirmed ("35 U.S. Code § 271—Infringement of patent," 1952). Given these risks, 3D printing services such as Shapeways have already attempted to protect themselves from liability by articulating within their terms of service that they shall not be held liable for any legal infringement which occurs as the result of users' behavior (Shapeways, 2019).

The potential liabilities of platforms that facilitate 3D printing activities recall debates regarding online service providers (OSPs) such as YouTube, Amazon, and eBay. Section 512 of the Digital Millennium Copyright Act outlines the safe harbor provisions for OSPs. These provisions protect the OSP from liability for all monetary relief for direct, vicarious, and contributory infringement as long as OSPs follow specific prerequisites such as having a system in place which deals with copyright infringing users and actively responding to Digital Millennium Copyright Act (DMCA) takedown notices. However, while previous cases such as MGM versus Grokster, Perfect 10 versus Amazon and the ongoing Viacom versus YouTube focused on the copyright liability of the service providers, the question of whether safe harbors can be extended to platforms which serve the 3D printing community may need to be expanded to cover both patent and copyright. The lawsuit filed against Kickstarter was eventually dropped by 3D Systems in 2013 (Weinberg, 2014). However, had the lawsuit continued, this could have had serious implications not just for 3D printing companies, but the hundreds of other hardware and device startups which use Kickstarter and other crowdfunding platforms.

2.3 Copyright Law

The US Copyright Office defines copyright as “a form of protection provided by the laws of the United States (“17 U.S. Code § 102 - Subject matter of copyright,” 1976); US Copyright Office to the authors of ‘original works of authorship’, including literary, dramatic, musical, artistic, and certain other intellectual works” (US Copyright Office, 2019). Copyright law protects works fixed in a tangible form of expression, including pictorial, graphic, sculptural, and audiovisual works (US Copyright Office, 2019). As soon as a work is created, it is automatically protected by copyright law. Creators do not need to register their works with the US Copyright Office in order to receive this type of legal protection, although filing for copyright will make it easier for the creator to pursue legal action in the event of infringement. With some exceptions like fair use, copyright owners hold exclusive rights to reproduce and distribute copyrighted works as well as to display and perform a work publicly.

While design patents and copyrights both protect aesthetics, design patents generally protect items that are considered utilitarian, while copyrights protect works that are considered non-utilitarian. Utilitarian items are those that are intrinsically functional. One exception to this general rule is the separability doctrine of copyright law, which articulates that aesthetic elements of a utilitarian item can be protected by copyright if they are physically or conceptually separable from the functional elements of an object (Mazer v Stein, 1954 [347 US 201]). Copyrights and patents are different for several significant reasons. Potential innovators must formally apply for a patent with the USPTO in order for their inventions to receive legal protection (U.S. Patent and Trademark Office, 2019). Patents have a significantly shorter term of protection—20 years from the filing date for a utility patent filed after 8 June 1995 and 14 years from the filing date for a design patent (Leahy-Smith America Invents Act, 2011). Once a patent expires, it cannot be renewed; its content enters the public domain. Copyrights, on the other hand, have a much longer protection term—for works created after 1 January 1978, the length is the life of the author plus an additional 70 years (U.S. Copyright Office, 2019).

Companies have already pursued legal action against individuals on the grounds of perceived copyright infringement. Such cases have also taken place between individual 3D printing users. For example, in 2012, Thomas Valenty, a 3D printing user, received a cease and desist order from Games Workshop, the company that owns the rights to the tabletop game Warhammer. Valenty was required to take down the designs he had created of several of the characters in the game from Thingiverse or risk further legal action (Thompson, 2012).

In November 2014, the public interest non-profit organization, Public Knowledge filed a Digital Millennium Copyright Act exemption request which would make it legal for individuals to use third party feedstock for their 3D printers. This is known as 3D printing's first DMCA request. This exemption request was particularly timely because as the market for desktop, consumer-oriented 3D printers has grown, one can observe an increase in the variety and number of 3D printers that are marketed as more turnkey and designed for the non-technical user in mind. Accordingly, these printers utilize proprietary printer cartridges and leverage Technical Protection Measures (TPMs) that would require individuals to hack or manipulate the hardware or software of the 3D printer in order to circumvent these technical barriers.

The action filed by Public Knowledge was the first formal DMCA exemption request specifically about 3D printing, however, the technology is no stranger to the battleground of intellectual property. This includes patent issues related to the hardware and copyright and trademark issues related to the digital files used to 3D print the physical objects.

Section 1201(a)(1) of the copyright law requires that every three years, the Librarian of Congress should determine whether there are any classes of works that will be subject to exemptions from the statue's prohibitions against circumvention of technology that controls access to a copyrighted work. Thus, submissions for DMCA exemption requests are accepted every three years (U.S. Copyright Office, 2017). While the Copyright Office has the sole authority of making recommendations to the Librarian of Congress regarding whether DMCA exemption petitions submitted should be accepted, the National Telecommunications & Information Administration (NTIA) has a statutory role in the process of reviewing the submitted exemption petitions. This means the NTIA assists the Copyright Office in collecting and reviewing the public comments. In a later phase of this public comment process, NTIA will weigh in with detail on these exemptions through a letter to the Register of Copyrights. In the 2012 DMCA exemption process, NTIA's letter to the Copyright Office was 30 pages with 200 some footnotes (NTIA, 2012).

The review process for the exemption request on 3D printing was multi-phased, as typical of other exemption requests. Comments in support of the petition could be submitted online until February 6, 2015 giving individuals in favor of the exemption just under 3 months to have their voices heard. Comments in opposition of the petition were given an additional month and a half and were due on March 27, 2015. Comments from supporters of particular proposals and parties that neither supported nor opposed a particular proposal could submit their thoughts until May 1, 2015. The design of this rulemaking process is meant to provide stakeholder organizations, the user community and other members of the general public with the opportunity to weigh in on the issues at stake. After each phase of the process ended, comments from this phase were released to the public for response. In addition to opportunity for stakeholders to weigh in online, two in-person hearings were held before the Librarian of Congress made her final decision about the Petitions in October 2015.

In October 2015, the NTIA sent a letter to the Register of Copyrights at the Library of Congress providing their formal recommendation on this and other DMCA exemptions (NTIA, 2015). NTIA expressed its support of an exemption that would apply across all types of 3D printing use-commercial, non-commercial and consumer and an exemption that would permit circumvention of a variety of TPMs in order to use non-manufacturer-approved feedstock. It also referenced the Lexmark Int'l. Inc. v. Static Control Components, Inc. case as a prior ruling in alignment with NTIA's recommendation.

2.3.1 Copyright and 3D Models

In 2013, an organization called Defense Distributed successfully designed and manufactured the first functional, 3D printed gun called the Liberator, and subsequently open sourced the design files for the Liberator handgun online, informed by the notion that this was an exercise in free speech and the right to bear arms (Hutchinson, 2013). Within 3 days of the files being posted, the U.S. State Department Office of Defense Trade Controls Compliance issued Wilson a letter noting that his actions were not in compliance with the International Traffic in Arms Regulations, which controls the trade and export of firearms. Defense Distributed was forced to take down the files, but the file was downloaded more than 100,000 times and copies of the files were subsequently posted on other sites for downloading (Greenberg, 2013). In 2015, Defense Distributed worked with the Second Amendment foundation to file a federal lawsuit in Texas against the State Department (Defense Distributed vs. State Department), with the goal of regaining the ability to openly publish its designs for firearms (Farivar, 2018b). In June 2018, an unexpected settlement was established between the Department of Justice and Defense Distributed that would have brought a multi-year legal battle to an end (Farivar, 2018b; Farivar

& Mattise, 2018, 2018). The files were reposted by Defense Distributed on DEFCAD, the online repository the organization created to share digital files for firearms and parts at the end of July. This settlement meant that the federal government agreed to alter the export laws in question. However, eight states quickly filed a lawsuit (Washington, Connecticut, Maryland, New Jersey, New York, Oregon, Massachusetts, Pennsylvania and the District of Columbia) to prevent the files from remaining on the Internet (Farivar, 2018). A federal judge in Seattle then overturned the ruling, articulating that the files should remain offline in order to meet U.S. export laws (Farivar, 2018a, 2018b). Several weeks later, Defense Distributed announced that they would comply with the federal court order preventing them from distributing the digital design files for the firearms internationally but would be selling the files in the U.S. for a suggested price of $10. Initially, the files would be sent to U.S. customers on a flash drive, with the possibility of expanding to email and direct downloading. Wilson articulated, "I'm happy to become the iTunes of 3D guns if I can't be Napster" (Farivar & Mattise, 2018). At the time of this writing, Wilson has stepped down from his role as CEO of Defense Distributed due to an unrelated sexual assault case against him (BBC News, 2018).

Scholars have asserted a way Defense Distributed may permanently be prevented from making its digital designs for 3D printed guns publicly available through copyright law. The written code of software programs is protected by copyright law and similarly, digital design files contain written code. Thus, Cody Wilson, the creator of the digital design files for the 3D printed guns and founder of Defense Distributed, possesses copyrights for the digital designs. Previous legal cases suggest that copyrights are subject to the Takings Clause of the Fifth Amendment, which articulates that the federal, state, or local government can use eminent domain to take ownership of the copyright. The grounds upon which this clause could be enacted could be on the basis of arguing that taking the copyrights would be in the public interest (Duan, 2018).

Changes to current IP law in and outside of the U.S. are affecting how individuals may be able to use 3D printing and the kinds of objects they are able to design and print with them. In 2016, the UK extended copyright terms to 70 years beyond the life of the designer for industrially manufactured artistic works. This included objects such as furniture and other items that could have both artistic and functional value. Previously, Section 52 of the Copyright, Designs and Patents Act 1988 ("section 52 CDPA") contained an exception which limited copyright protection for artistic works when they have been industrially manufactured. If more than 50 copies of these artistic works were produced, the length of copyright protection was 25 years beyond the life of the creator. "The Government wishes to provide the full term of copyright protection for artistic works, whether created as a one-off or industrially manufactured and sold to consumers across the UK. This will be achieved by repealing section 52 of the Copyright, Designs and Patents Act 1988 which reduces the term of copyright protection for artistic works which are produced through an industrial process (Intellectual Property Office, 2016)." The successful repeal of this part of the Act was met by concerns from advocates of open access to knowledge, leaders of the design and Maker communities and legal experts who articulated how this change would restrict how individuals who use 3D printing to produce their own furniture, leaving them vulnerable to prosecution (Intellectual Property Office, 2016; Moody, 2016; Rick Falkvinge, 2016).

A 2017 case that was not specifically about 3D models could have a significant impact on the ways U.S. copyright laws will apply to digital design files. In Star Athletica v. Varsity Brands, the Supreme Court ruled that the designs of cheerleading uniforms could be copyrighted (Mullin, 2017). This was on the basis that creative elements of such uniforms (which are copyrightable) could be separated from utilitarian aspects (which are not copyrightable). Varsity Brands, the largest producer of cheerleading uniforms in the world, accused competitor Star Athletica of violating copyright protected designs of its uniforms. While Star Athletica asserted that the chevrons and stripes on a uniform were functional, in that they identified the individual as a cheerleader, the district court agreed with Star Athletica, acknowledging that separability of creative and utilitarian elements could not be established. However, the US Court of Appeals overturned this ruling (*Star Athletica v. Varsity Brands*, 2017). The Supreme Court eventually agreed to take up Star's request to review this case with the support of an amicus brief by three 3D printing companies (Shapeways, Formlabs and Matter and Form). The amicus brief described how having a single, predictable test for conceptual separability was critical to many different industries and sectors beyond apparel and has significant implications for 3D printing. The brief also connected Star Athletica v. Varsity Brands to the existing uncertainty around the ways in which copyright law apply to digital designs and the 3D printed objects from these designs. "Since Congress enacted the Copyright Act of 1976, the law has recognized that the creative parts of useful articles are copyrightable to the extent that they are either physically or conceptually separable from the object itself. Today, there are numerous inconsistent, conflicting tests for conceptual separability that create a great deal of uncertainty and confusion for determining which parts of these objects qualify for copyright protection. The result is that both practitioners steeped in the law and legally unsophisticated users engaged in 3D printing cannot reliably identify which parts of a mixed object might be protected by copyright" (*Star Athletica v. Varsity Brands*, 2017).

2.3.1.1 Originality and Fixation

Two of the fundamental tenets of copyright law are originality and fixation. New questions arise when we consider what originality means in the context of 3D printing activities. US copyright law considers a work to be original if it contains some modicum of creativity and is created independently by the author (Subject Matter of Copyright [17 US Code § 102], 1976). But the question of originality becomes more difficult to define, given that a large number of 3D printing users openly share the object design files they create online. Other users may then take these designs, modify them in varying degrees and re-post them as their own designs. Would this second group of users have copyright protection over these modified designs? In other words, are their modifications substantial enough to be considered original? These subsequent designs would most likely be considered derivative works. According to US copyright law, the author of the creation has the exclusive rights to prepare derivative works unless the author grants others the permission to produce them (Compilations and Derivative Works [17 US Code § 103]), 1976). A derivative work is defined as "consisting of editorial revisions, annotations, elaborations, or other modifications, which, as a whole, represent an original work of authorship" (Compilations and Derivative Works [17 US Code § 103]), 1976).

2.3.1.2 Creative Commons

Rather than preventing others from using what they have created, many creators of digital object designs use Creative Commons (CC) licensing to encourage individuals to use their works in a manner that ensures that original authors receive credit. Creative Commons is a non-profit organization designed to facilitate the sharing of knowledge and creativity through free copyright licenses that enable creators to give the public permission to use their works under specified conditions (Creative Commons, 2019). Founded in 2001, Creative Commons began as an initiative aimed at providing creators with a spectrum of choices around how they could share their copyrightable works with others who might like to use them. This was informed by the understanding that traditional copyright law and on-going debates about creative ownership promoted extremes. On the one hand, copyright enforced works prevented others from using a work under any circumstances without explicit permission from the creator or risk potential legal ramifications. On the other hand, a world without copyright could mean that the works of creators would be freely available for anyone to use without properly compensating and crediting these individuals. In 2002, Creative Commons introduce a set of licenses based on the GNU General Public License of the Free Software Foundation. The Creative Commons (CC) licenses were designed to be used for other creative, copyrightable content such as music, film, stories, photography and websites. The CC licenses provided a creator with various choices for specifying how and under what conditions another person could use his/her work. For example, the Attribution By license allows anyone to "distribute, remix, tweak, and build upon your work, even commercially, as long as they credit you for the original creation" while the Attribution-NonCommercial-ShareAlike license "lets others remix, tweak, and build upon your work non-commercially, as long as they credit you and license their new creations under the identical terms" (Creative Commons, 2019).

Creative Commons licenses have a three-layer structure: 1) Legal code- norms and rules of each license are expressed in full legal language; 2) Commons deed- Each license is also described in plain language, making it easy for everyone else to understand the permissions and restrictions; 3) Machine-readable code- Each license features code which makes it easy for the Internet (software platforms, search engines, etc.) to identify which works are CC licensed (Stacey & Pearson, 2017).

What initially began as a collaboration between scholars at MIT, Berkman Center for Internet & Society at Harvard Law School and Stanford Law School Center for Internet and Society led by Lawrence Lessig, Hal Abelson, and Eric Eldred and others has 20 years later become Creative Commons- a non-profit organization and global community which "develops, supports, and stewards legal and technical infrastructure that maximizes digital creativity, sharing, and innovation" (Creative Commons, 2019; Lessig, 2004). Over the years Creative Commons has expanded its scope of programs, activities and tools as the usage of CC licenses has grown internationally and as new and critical issues around copyright and IP emerged. This includes a certification program for educators and librarians aimed at providing a more thorough understanding about CC licenses, their use and the principles and values behind Creative Commons. Creative Commons also maintains a Global Network consisting of 289 community members who serve as CC representatives in over 60 countries to continue to facilitate collaboration internationally and grow the number of individuals and organizations using CC licenses to share their works. Creative Commons has also actively advocated for or against specific policy issues- speaking out against the Trans-Pacific Partnership's restrictive copyright provisions, engaging national governments in developing open education policies and weighing in on EU copyright reform. To date, there are more than 1.4 billion creative commons licensed works, compared to 140 million licensed works in 2006. The significant increase in the number of works can in large part be attributed to large online platforms such as YouTube and Wikipedia which house a massive amount of creative content. In 2017, YouTube alone had 49 million CC licensed works, while Wikipedia had 46.7 million works (State of the Commons, 2017). In addition to the CC licenses, the organization has also developed other tools, such as the CC search engine, which it launched in 2017. The search engine is designed to make it as easy as possible for individuals to search for CC licensed content online.

Creative Commons has been studied and researched by numerous scholars in an effort to gain more insight into the dynamics of the CC community and how it functions, the role of CC in cultivating and fostering a digital commons and the role of CC in redefining IP. In *Made with Creative Commons*, Paul Stacey and Sarah Hinchliff Pearson discuss the development of the digital commons and the development of Creative Commons within the historical context of other commons- resources such as water, fish and grazing land which were managed by people in the community before they were controlled by the state or market (Stacey & Pearson, 2017). While scholars like Garrett Hardin cautioned that individuals in a commons would each leverage the commons for their own personal benefit until the particular commons would be exhausted, Elinor Ostrom’s Nobel Prize winning research on common pool resources demonstrated that natural resource commons could be more effectively managed by local communities without the intervention of the government or companies (Hardin, 1968; Ostrom, Burger, Field, Norgaard, & Policansky, 1999). While Hardin and Ostrom’s work focused on resources that have a finite supply or are depletable, the Internet and the development of other digital technologies has created a digital commons with content that can be used by more than one person at a time without being depleted, creating a different kind of commons. Stacey and Pearson argue that while the digital commons do not suffer from the risk of depletion as other natural resource commons might, “An absence of a theory or model for how abundance works has led the market to make digital resources artificially scarce” (2017). In his earlier work, Creative Commons co-founder Lessig positions the need for Creative Commons as a counterpoint to the changes in copyright law over the years that have made it increasingly difficult for the public to access and use creative works. This includes the extension of the length of copyright protection, the expanded scope of copyright in terms of the kind of content that can be protected and the broader reach of copyright regulation in the digital age (Lessig, 2004).

“The free society that defines our tradition is increasingly a permission society. The free culture that defined our birth is increasingly an owned culture- where the ability to cultivate that culture is a function of the permission you can get from the culture owners” (Lessig 2004). Lessig describes how the world is divided into three camps- those that believe in total control or all rights reserved, those that want no restrictions and no rights at all and those that believe in a more moderate approach with some rights. Creative Commons is Lessig’s approach has been to foster an environment for this third option. “The idea here is that we need to build a layer of reasonable copyright law, by showing the world a layer of reasonable
copyright law resting on top of the extremes” (Lessig 2004).

Carroll describes the ways in which CC licenses have both disintermediating and reintermediating roles on the Internet- reintermediating in the sense that Creative Commons facilitates the creation of new services and new communities around licensed creative content and disintermediating because the licenses enable end-to-end transactions of copyrighted works from the creator to another user (Carroll, 2006). Loren has focused more on the ways in which the use of CC licenses has enabled users to place their works in what she calls a "semicommons"- defined as a commons which "embodies both important private rights and important public rights that dynamically interact" (Loren, 2006). Here she argues that in order for this semicommons to thrive and in order to encourage more users to leverage CC licenses to share their work, it is critical for the law to give equal importance to both the private rights of the copyrighted work and the public rights facilitated by the CC license (Loren 2006). In contrast to scholars who have generally viewed Creative Commons as a promising solution to addressing the widely recognized issues with the digital commons and copyright law, Niva Elkin-Koren articulates her skepticism of Creative Commons' strategy to rely on property rights and on viral contracts to promote free culture (Niva Elkin-Koren, 2006). One of the main issues Elkin-Koren cites is her concern that Creative Commons reduces open culture to the concept of enabling authors to control their works and who will have access to this content through licenses and that the licenses could create confusion and discourage usage of content because of their lack of standardization. However, it is unclear what the author means when she mentions a lack of standardization.

With the growing distribution of digital content and digital object designs and the cycle of sharing this distribution creates, the process of mediating ownership through licensing becomes more relevant. But the reality is that while CC licensing offers a more nuanced way for creators to share their work and enable others to use it, it is difficult for creators to monitor whether others are using their works according to the guidelines set forth by a particular license. Critics of Creative Commons have expressed that the licenses cannot be fully functional if there is no system or mechanism in place for monitoring whether users are abiding by the licenses of these works.

Creators who have chosen to leverage Creative Commons to share their works have also developed business models which simultaneously enable them to distribute their creations while generating revenue around their work. This concept is not new- there are numerous examples of companies that have successfully developed out of the open source software community, such as Red Hat, which develops and sells open source, Linux based enterprise solutions and was acquired by IBM in 2019 for $32 billion (Volpi, 2019). Stacey and Pearson examined the different ways that Creative Commons users and entrepreneurs have developed open business models in areas ranging from hardware and online repositories of news and data to songs, games and furniture designs. Through a series of interviews with the creators and co-founders of these businesses, Stacey and Pearson discovered that “Being Made with Creative Commons may be good for business, but that is not why they do it. Sharing work with Creative Commons is, at its core, a moral decision. The commercial and other self-interested benefits are secondary. Most decided to use CC licenses first and found a revenue model later” (2017).

The undertaking of attempting to track who has been using a creation and how thoroughly can be a massive challenge in an era when users are from many different countries and are using a plethora of different sites and outlets to share their creations.

2.3.2 First Sale Doctrine and Exhaustion

According to U.S. law, the first sale doctrine articulates that an individual who purchases a copyrighted work, patented item or trademarked product from the IP holder receives the right to sell, display or otherwise dispose of that particular copy, indicating that the rights of the original IP holder would be terminated or exhausted upon this sale transaction (17 U.S.C. § 109). In this sense, the first sale doctrine asserts the ability for a consumer that has acquired an IP protected work or product to be able to assert full control, governance and use over a technology that he/she has purchased. However, various cases have called into question how the first sale doctrine applies to different technologies and in different contexts. The circumstance under which the first sale doctrine applies must clearly be a sales transaction in which full ownership of the work or product is being transferred to an individual- the first-sale doctrine does not apply to instances where a work is licensed or loaned out temporarily. “Notwithstanding the provisions of subsection (a), unless authorized by the owners of copyright in the sound recording or the owner of copyright in a computer program (including any tape, disk, or other medium embodying such program), and in the case of a sound recording in the musical works embodied therein, neither the owner of a particular phonorecord nor any person in possession of a particular copy of a computer program (including any tape, disk, or other medium embodying such program), may, for the purposes of direct or indirect commercial advantage, dispose of, or authorize the disposal of, the possession of that phonorecord or computer program (including any tape, disk, or other medium embodying such program) by rental, lease, or lending, or by any other act or practice in the nature of rental, lease, or lending” (17 U.S.C. § 109). One recent case that sought to address these issues was Impression Products, Inc. vs Lexmark International, Inc.

This case confirmed that a firm holding a patent, in this case Lexmark, exhausts its rights to enforce the patent once it sells the product to which the patent applies within the U.S., but that its rights as a patentee are not exhausted for sales abroad (*Impression Products, Inc. Vs Lexmark International, Inc.*, 2017). Impression Products is a company which, acquired Lexmark cartridges that had been replaced with microchips from a third party, enabling these cartridges to be refilled and reused. Impression Products acquired these refilled cartridges abroad and then sold them in the U.S. Lexmark sued Impression Products and other remanufacturers for patent infringement, related to two kinds of cartridges. The first were the cartridges that were part of Lexmark's Return Program (formerly the prebate program) sold in the U.S and the second were the cartridges that were purchased abroad and then imported into the U.S. to be sold. Impression Products responded by articulating that once Lexmark sold the cartridges, it had exhausted its patent rights both in the U.S. and abroad, giving Impression Products the ability to modify the cartridges so that they could be refilled and resold. The Supreme Court held that even though Lexmark had sold the Return Program cartridges under certain restrictions (that participating customers would agree to use the cartridges only once and return them to Lexmark, receiving a 20% discount), this did not mean that Lexmark retained its patent rights affiliated with the cartridges- once the cartridges were sold, Lexmark had exhausted these rights. With regards to the cartridges sold abroad, the Supreme Court asserted that because patent rights are territorial, a patentee's rights are not exhausted with regards to the sale of products abroad (*Impression Products, Inc. Vs Lexmark International, Inc.*, 2017). When an inventor files for a patent in the U.S., that patent does not automatically provide protection outside of the U.S.

Justice Roberts provided the opinion of the court and below are several excerpts that are particularly relevant to questions that have emerged regarding whether third parties may modify and resell "proprietary" printer cartridges for 3D printers.

> *When a patentee sells one of its products, however, the patentee can no longer control that item through the patent laws—its patent rights are said to "exhaust."*

> *The exhaustion rule marks the point where patent rights yield to the common law principle against restraints on alienation. The Patent Act promotes innovation by allowing inventors to secure the financial rewards for their inventions. Once a patentee sells an item, it has secured that reward, and the patent laws provide no basis for restraining the use and enjoyment of the product. Allowing further restrictions would run afoul of the "common law's refusal to permit restraints on the alienation of chattels."*

> *Either way, extending the patent rights beyond the first sale would clog the channels of commerce, with little benefit from the extra control that the patentees retain. And advances in technology, along with increasingly complex supply chains, magnify the problem.*

> *Patent law is territorial. When an inventor receives a U. S. patent, that patent provides no protection abroad. See Deepsouth Packing Co. v. Laitram Corp., 406 U. S. 518, 531 (1972) ("Our patent system makes no claim to extraterritorial effect."). See also 35 U. S. C. §271(a) (establishing liability for acts of patent infringement "within the United*

States" and for "import[ation] into the United States [of] any patented invention"). A U. S. patentee must apply to each country in which she seeks the exclusive right to sell her invention.

Perzanowski and Schultz describe the ways in which products that are digital or are accessed or managed digitally have called into question what true ownership means and how the current arrangements developed and implemented by companies can differ from those products that are physical and "non-technological" (Perzanowski & Schultz, 2016). They articulate, "How did our rights in media goods become so unstable and insecure? Part of the answer is technology. Cheap remote storage, high-speed mobile network connections, and nearly ubiquitous computing devices like tablets and smartphones have facilitated new ways of distributing media. Digital downloads, cloud storage, and streaming services offer convenience, instant accessibility, and lower prices to consumers….At the same time, aggressive intellectual property laws, restrictive contractual provisions, and technological locks have weakened end user control over the digital goods we acquire" (Perzanowski & Schultz, 2016).

2.4 Other previous legal cases focused on technology related to 3D printing

To understand how the legal system might address the legal questions and tensions that have emerged or may develop around 3D printing, it is also critical to examine previous legal cases which dealt with analogous issues. The ways in which these cases have played out and their final rulings can provide one with insights into how similar questions specific to 3D printing could be addressed in ways that minimize the over governance of the technology while fostering an environment which encourages the creation of knowledge through appropriate incentives.

2.4.1 Sony Corp. of America v. Universal City Studios, Inc.

With Sony's introduction of the Betamax video tape recorder in the mid-1970s, individuals now had the ability to tape a program by making a copy that would be stored to a video cassette which could then be viewed later. At the center of this case was the question of whether making individual copies of complete television shows for the purposes of "time-shifting" was copyright infringement. Universal sued Sony for copyright infringement, alleging that because consumers could use the Betamax to record copyrighted works owned by Universal, Sony could be liable for any copyright infringing activities committed by Betamax customers (*Sony Corp. Of Am. V. Universal City Studios, Inc.*, 1984). This case was initially argued before the District Court, which found that noncommercial home use recording could be considered fair use of copyrighted works and would not be considered copyright infringement. Because this activity was not an act of copyright infringement, the question of Sony's liability was no longer relevant. The ruling was overturned by the Ninth Circuit Court, but the Supreme Court eventually overturned this decision, affirming that noncommercial home recording of television broadcasts for the purpose of "time-shifting" was fair use (US Copyright Office, 2019). In addition, the Court concluded that Universal did not substantively prove that usage of the Betamax to record their copyrighted content negatively impacted the company's business from a commercial standpoint- it could be argued that the ability for individuals to go back and watch a program that they otherwise would have missed actually enlarged the viewing audience that Universal would have for its shows and films.

2.4.2 A&M Records, Inc. vs. Napster, Inc.

In 1999, a new company called Napster made it possible for individuals to quickly and easily distribute digital audio files, primarily MP3s, through peer-to-peer file sharing. Using P2P file sharing, Napster provided a main server where files were indexed and searches were carried out, but the files would stay on hosts' computers and transferred peer to peer. Napster is broadly credited with playing a critical role in launching and growing the shift to digital music. Less than one year after launching, Napster had a community of 20 million users, with more than 14,000 songs being downloaded every minute (Lamont, 2013). At its peak, Napster had 57 million users (Lamont, 2013). The growing concerns from record labels, recording industry executives and copyright holders whose music was being widely distributed at no cost to users came to a head when the Recording Industry Association of America (RIAA) sued Napster on behalf of several record labels in Dec. 1999, just 7 months after the company had launched. The RIAA's primary claims in the lawsuit included contributory and vicarious copyright infringement based on the fact that Napster provided the program which enabled users to download copyrighted music files. Napster's defense against this claim was that the digital files did not contain copyrighted information, and as a company there was no way to tell which of the individual files being distributed would be engaging in copyright infringement. Additional defense arguments provided by Napster included that their users have a fair use exemption from direct infringement, users are exempt from infringement through the Audio Home Recording Act and Napster should be considered an Internet Service Provider and thus limited in liability through the Digital Millennium Copyright Act (Blackowicz, 2001). "A federal judge and an appeals court in San Francisco both ruled in 2002 that Napster was liable for contributory or vicarious copyright violations, because it was allowing millions of users to download music for free" (Kravets, 2009). This case was significant for several different reasons. It prompted the District Court and Court of Appeals for the Ninth Circuit to address some of the key questions that were addressed in the Sony Corp. of America v. Universal City Studios, Inc. case but within the context of a new technology with some similar capabilities, but distinctively different functionality. The courts found that a number of Napster's claims around fair use could not be substantiated- users downloading files for sampling, to hear a song before purchasing it, was not deemed to be fair use because "samples" were actually permanent copies of entire songs or media. In cases where an individual already previously purchased or owned a CD containing a song that he/she then downloaded through Napster ("space shifting"), this action enabled other users who might not have previously purchased the song within the Napster system to be able to access it, which could not be considered fair use. The Courts acknowledged that peer-to-peer file sharing services and Napster's software could be used for both infringing and non-infringing uses and consistent with the Sony Betamax case, found that this alone could not be grounds for ruling that Napster was at fault. However, the Ninth Court ultimately found that "Napster knew or had reason to know of its users' infringement of plaintiffs' copyrights."

2.4.3 Metro-Goldwyn-Mayer Studios Inc., et al., vs. Grokster, LTD., et al.

Several years later, peer-to-peer file sharing companies Grokster and Morpheus were sued by a group of 28 large entertainment and media corporations claiming that both companies violated the Copyright Act by distributing software which enabled users to engage in copyright infringement by downloading protected works. Unlike Napster, the technical infrastructure for Grokster and Morpheus enabled users to connect directly with one another- no requests were routed through a central server as was the case with Napster. "Napster provided a centralized service to facilitate music file sharing, following the classic Internet model in which the consumer connected to Napster's central Web site to transact business through Napster's server. Grokster and other similar peer-to-peer operations, however, don't involve a middleman"

(Smolla, 2004). This was one distinction that played a critical role in the district court and Ninth Circuit Court of Appeals ruling that these file sharing services could not be held liable for copyright infringement committed by their users. The courts articulated that in order for a provider to be held liable, it must be aware of infringements and demonstrate that it failed to block these activities. When the case came before the U.S. Supreme Court in 2005, however, these decisions were overturned. The question they sought to answer was, "Under what circumstances can the distributor of a product capable of both lawful and unlawful uses be liable for acts of copyright infringement by third parties using the product?" (*MGM Studios vs. Grokster*, 2005). The Supreme Court reviewed this case relative to the former Sony Betamax case and found that unlike the latter, there were very few examples of fair use or substantial non-infringing uses. In addition, there was evidence to support that both service providers actively promoted copyright infringing activity through various documentation and promotional materials (*MGM Studios vs. Grokster*, 2005). Thus, the court found that Grokster and Morpheus could be held liable for contributory infringement via inducement.

2.4.4 Lexmark International, Inc. v. Static Control Components, Inc.

Large laser and inkjet printer manufacturer Lexmark creates the toner cartridges for their printers. While there were some cartridges that customers could refill themselves through third party companies, in an effort to incentivize customers to continue to purchase printer cartridges through Lexmark, the company created a prebate program which allowed a consumer to purchase several specific cartridges at a significant discount on the premise that the consumer would only use the cartridge once and return it to Lexmark to be recycled. Lexmark also promoted the program as an initiative that would help the environment. A prebate cartridge contained a chip that included a 55-byte computer program (the "Toner Loading Program") which communicated with a "Printer Engine Program" built into the hardware of the printer (*Lexmark Int'l Inc. V. Static Control*, 2014). The Toner Loading program calculated and monitored how much toner was used during printing and when the calculations concluded that the Lexmark supply of toner was finished, the printer would stop working, even if the cartridge was refilled with ink. The Lexmark printer required a "digital handshake" with the chip, which would engage an encrypted authentication sequence and required a checksum on the chip to match a value stored elsewhere on the chip in order for the printer to print using that cartridge. Static Control Components (SCC), a technology company, developed a chip that duplicated the digital handshake required to ensure that the printer would function. This chip also included a copy of the Toner Loading Program (*Lexmark Int'l Inc. V. Static Control*, 2014). These SMARTEK chips could replace the original Lexmark chips in the prebate cartridges so that they could be refilled. SCC sold these chips to third party cartridge refilling companies. In 2002, Lexmark sued SCC, accusing the company of violating both the Copyright Act of 1976 and the Digital Millennium Copyright Act, based on the creation and sale of its chip which contained the copied Toner Loading Program. SCC filed a counterclaim, articulating that Lexmark had violated the Lanham Act by engaging in false advertising that negatively affected Static Control's business. These violations according to the SCC included the accusation that Lexmark misled users into believing that they were legally bound by the prebate terms to return their cartridges after a single use and that Lexmark notified companies in the toner cartridge remanufacturing industry that it was illegal to sell refurbished prebate cartridges, in particular, by leveraging SCC components. The District Court ruled that SCC did not have "prudential standing" to assert the Lanham Act claim, but the Sixth Circuit used a "reasonable interest" test and reversed this ruling, which was also confirmed by the Supreme Court (*Lexmark Int'l Inc. V. Static Control*, 2014). This confirmed that SCC was entitled to pursue a legal case against Lexmark based on relevance to the Lanham Act.

2.5 Trademarks and 3D Printing

The USPTO defines trademarks as, "a word, phrase, symbol, or design, or a combination thereof, that identifies and distinguishes the source of the goods of one party from those of others" (USPTO, 2018). Historically, trademarks have enabled consumers to properly identify the company or manufacturer of a particular item. Trademarks are often used to symbolize a particular brand, which stands for a specific set of values which collectively help a consumer make decisions about what products to purchase and helps them understand the kind of product they're getting in terms of characteristics like quality. "Over time, the law has come to recognize that trademark law serves two primary and interrelated functions. First, it protects manufacturers' incentives to invest in quality goods by preventing an imitator from adopting the same mark and thus diverting sales from the first manufacturer. Second, trademark law protects consumers from deception by allowing a trademark to connote a specific (if anonymous) source, thus enhancing information quality on which consumers rely" (Osborn, 2017). Because 3D printing democratizes both design and manufacturing, the connotations of manufacturing quality that would previously be embedded in a trademark become somewhat less relevant in the context of 3D printing. Given the large volume and speed at which digital design files are exchanged online, Osborn articulates that perhaps the kind of information included in trademarks within these files should evolve to accommodate the unique aspects of the technology (Osborn, 2017). Trademarks within digital design files could include critical pieces of information like the name of the creator of the file and the website from where it was downloaded.

3 CHAPTER 3- Theoretical Framework

The theoretical framework used for this research primarily draws on a combination of theories and concepts from Science and Technology Studies (STS) and Innovation Studies. I seek to examine the ways in which social, technical, legal and economic constructs are playing a role in the development of 3D printing and the ways in which 3D printing are actively changing these aspects. As a field, STS situates science and technology within a social context, creating opportunities for one to examine the ways in which institutions, composed of processes, practices, infrastructures, norms and values can act upon a technology and the ways in which that technological artifact can change, shift or evolve these institutions. STS also provides analytical, reflective concepts for my research as it acknowledges the importance of individual and collective actors in the application, development and innovation of a technology. Further, it considers the different ways that an actor may play a role in the life of a technology beyond passive use. STS helps us to understand the ways in which technologies are woven into societies and how this dynamic, ongoing process is filled with tensions, disruptions and breakthroughs, including the solving of problems and the creation of new ones. The STS literature provides a foundation for and informs central questions closely aligned with the research problem this dissertation is focused on, such as: How is technology governed? How does technological innovation occur? What expertise do policymakers require to understand the dynamics of institutions and stakeholders in order to develop regulatory policies that ensure broad access to technology? What lessons can we learn from the history of technologies that can inform current socio-technical issues?

Social construction of technology, recursive publics and free innovation were chosen as main theoretical concepts to use for this research because each of these possessed specific elements that enabled me to more deeply unpack, understand and describe the activities of 3D printing users specific to the questions I set out to answer around Creative Commons use. Rather than applying all three theoretical concepts evenly across the analyses for the interviews and case studies, I utilized these as interpretive tools in a toolbox, actively choosing to use a particular concept when it seemed most relevant and could provide additional insights to the situation at hand.

3.1 Social Construction of Technology

Within STS, Social Construction of Technology (SCOT) is a theory which describes the ways that users and other individuals which interact with a technological artifact play an active role in the development and evolution of the technology. These individuals include users, but also can include other individuals who come into contact with a technology in other ways, such as an advertiser or salesperson. SCOT asserts that users and technologies are co-constructed, as users exercise "interpretive flexibility," leading to different decisions about how the technologies will be used (or not used), how they will be changed (or not changed) within a situated context (Lindsay et al., 2005; Pinch & Bijker, 1984). From this perspective, users possess agency, which enables them to take an artifact that has been imbued with a set of assumptions by designers about how a technology should be utilized and is able to negotiate with the "script" that the designers have created and their attempts to "configure" users to interact with the technology in a specific way (Akrich, 1992; Woolgar, 1990). SCOT is a particularly relevant STS approach to understanding how innovation takes place throughout the development of a technological artifact. SCOT is centered around the idea that this development is an alternative of variation and selection, resulting in a “multi-directional” model (Bijker & Pinch, 1989). This perspective is aligned with the perspectives of scholars such as Stokes, Etzkowitz and Loet who attest that innovation can, but does not always take place linearly (Etzkowitz, H. & Loet L, 2000; Pinch & Bijker, 1984; Stokes, 1997). This multi-directional model is informed by “interpretive flexibility,” the different ways that social groups perceive the problem(s) that a particular artifact can solve and how this technology should be designed to solve these issues (Bijker & Pinch, 1989). These differences are driven by the fact that there is a subjectivity that always underlies the interpretation and understanding of facts. “By this we mean not only that there is flexibility in how people think of or interpret artifacts but also that there is flexibility in how artifacts are designed” (Bijker & Pinch, 1989). Because of this flexibility, individuals or groups of individuals may identify a new use or application for a technological artifact which might not have been conceived by the original creators or modify particular features of an artifact to change or enhance its functionality. Users and non-users of a particular artifact can make up these social groups, which are defined by a shared set of commonalities and interests that they possess relative to the technology. As specific social groups identify unmet needs or additional applications for an artifact, development takes place, with an artifact undergoing modifications that can lead to the addition or removal of features to address these issues. An artifact can be developed by multiple social groups simultaneously, so there can be any number of different versions of technological artifacts in existence at any point in time, as demonstrated by the evolution of the bicycle in the 1800s and early 1900s (Bijker & Pinch, 1989). It is important to note here that SCOT emphasizes that technological artifacts are developed and innovated upon within a social environment that ultimately molds these artifacts, but that this effect also goes the other way, with technologies changing the social environments in which they exist (Pinch &

Bijker, 1989).

A body of work builds upon SCOT and examines how users and non-users are important to the development of technological artifacts (Oudshoorn, Rommes, & Stienstra, 2004). While SCOT can be leveraged to more closely examine how users are agents of technological change, using semiotic concepts such as “configuration” and “script” enable one to understand how the designs of technologies configure users to utilize them in a particular way, based on how users have been pre-defined and the assumptions about how they will behave (Oudshoorn et al., 2004; Woolgar, 1990). As a result, a “script” is developed with regards to how these individuals will use the artifact, with constraints built into the design to ensure users stay “on script” (Oudshoorn et al., 2004; Woolgar, 1990). One observes that instances of innovation can take place when users overcome this configuration and deviate from the script. In these situations, such activities can lead to the creation of new technologies, but can also disrupt existing systems and structures.

There are a number of other theories and literature in the fields of Information Science and STS which will further expand the analysis of my research findings through SCOT. This includes literature on the role of experts in the process of policymaking around the use and access to technological artifacts and research on the governance of science and technology. Sheila Jasanoff has documented the role of scientific expertise in the policymaking process, illustrating a gradual shift from the technocratic to democratic perspective with regards to the role of science in policy. There are two dominant perspectives on the role of science in policy- technocratic and democratic (Jasanoff, 1998). The technocratic perspective embraces the idea that it is imperative to infuse the highest quality of science possible into the process by growing the role of the science expert. The democratic view asserts that policy can be improved by being more inclusive and integrating more perspectives, with an eye to broadening who can engage in the process to include not just professional scientists but those who may be directly affected by the particular policy or regulation at hand (Jasanoff, 1998). This development can also be observed when it comes to the role of the technology expert, which includes individuals who are engineers, computer scientists and other individuals with a technical professional and academic background. This democratic perspective does not discount the important role that technology experts can continue to play in providing critical knowledge in the policymaking process, but it is reflective of the ways in which specific technological artifacts have become more broadly accessible to the public, with individuals actively using the technology who would not traditionally be called experts, but who have significant experience and knowledge about a technology and its applications.

Reiner Grundmann has examined various interpretations of the role of experts and expertise in decision making within the knowledge society. In doing this, he recognizes that much of the STS research on this topic has neglected the basic question of how expertise is defined within the context of today's society (Grundmann, 2017). He asserts that in a knowledge society, the idea of who is an expert is redefined, with individuals who were formerly considered experts such as scientists in institutions like universities being supplanted by several different factors. These factors include suspicions that scientists and engineers use their positions to push specific agendas and the increasing number of individuals who are able to attend college and acquire the experiences that enable them to engage in issues that formerly only an elite group of individuals were able to participate in (Grundmann, 2017). Expertise has become much more ubiquitous, with society recognizing the value of different kinds of expertise, as described by a typology of expertise which distinguishes 3 types of experts that are needed in the decision making process: 1) scientific experts; 2) professional experts; 3) field experts. Grundmann articulates that in today's knowledge society, expertise must be viewed as relational- "essentially something delivered at the request of someone else who wants it. This makes expertise relational in a double sense: it relates to clients and it relates to their needs, which often is the need for guidance in decision-making." Thus, an individual could be a client in one context and an expert in another context (Grundmann, 2017).

For example, as the market for desktop, consumer-oriented 3D printers has grown, there has been an increase in the variety and number of 3D printers that are marketed as more turn key and designed for the non-technical user in mind (Peels, 2017). These printers utilize proprietary printer cartridges and leverage Technical Protection Measures (TPMs) that have prompted individuals to hack or manipulate the hardware or software of the 3D printer in order to circumvent these technical barriers (Public Knowledge, 2014). Consumers have been finding creative ways to circumvent these features including reprogramming the chip which keeps track of how much filament is in a cartridge so that it can be refilled and creating an adapter which allows you to connect a spool of generic filament to the printer even after the cartridge is empty (Benchoff, 2014a, 2014b). In November 2014, the public interest non-profit Public Knowledge filed a Digital Millennium Copyright Act exemption request which would make it legal for individuals to use third-party feedstock for their 3D printers (Public Knowledge, 2014). The concern expressed in the DMCA exemption request filed by Public Knowledge was that these activities, which involve "hacking" 3D printers in order to be able to use a non-proprietary feedstock, could make consumers liable based on the grounds of violating regulations around anti-circumvention of Digital Rights Management (DRM) mechanisms (Public Knowledge, 2014).

In other situations, tensions arise with regards to the actual objects that users design and print using 3D printers. One high-profile example of this case involves Defense Distributed, an organization founded in 2012 by Cody Wilson, who at the time was a law school student. Defense Distributed was initially created with the goal of researching, designing and producing firearms using 3D printing. In 2013, Defense Distributed successfully designed and manufactured the first functional, 3D printed gun called the Liberator, and subsequently open sourced the design files for the Liberator handgun online, informed by the notion that this was an exercise in free speech and the right to bear arms (Hutchinson, 2013). Within three days of the files being posted, the U.S. State Department Office of Defense Trade Controls Compliance issued Wilson a letter noting that his actions were not in compliance with the International Traffic in Arms Regulations, which controls the trade and export of firearms. Defense Distributed was forced to take down the files, but the file was downloaded more than 100,000 times and copies of the files were subsequently posted on other sites for downloading (Greenberg, 2013). In 2015, Defense Distributed worked with the Second Amendment foundation to file a federal lawsuit in Texas against the State Department (Defense Distributed vs. State Department), with the goal of regaining the ability to openly publish its designs for firearms (Farivar & Mattise, 2018; Montgomery & Urbina, 2018).

This example provides insights into the ways in which technological artifacts are interwoven and enmeshed with a society's values, norms, culture and legal system- touching upon gun control, the dual use nature of technology and the importance of technological governance. Examining this situation using SCOT, one can observe the ways in which a user has deviated from the "script" developed by the designers and manufacturers with regards to the ways in which 3D printing is intended to be used and the attempts by the provider of the technology to prevent a user from leveraging the technology in an unscripted and potentially illegal way. The initial 3D printer that Wilson used to prototype the early versions of the Liberator was being rented from 3D printing manufacturer, Stratasys. Upon learning that one of its printers was involved in the development of the Liberator, Stratasys cancelled its contract with Wilson and re-possessed the printer (Montgomery & Urbina, 2018).

3.2 **Recursive Publics**

The STS theoretical concept, "recursive publics," developed by Chris Kelty, provides an analytical lens through which to understand how users of a particular technology, further empowered by the Internet, have been able to transcend governments, networks and economies to develop their own mode of existence which supports and fosters the kind of reality that they believe in and desire. Originally developed as a theoretical tool used to gain insights into the cultural significance of Free Software, "[r]ecursive publics are publics concerned with the ability to build, control, modify and maintain the infrastructure that allows them to come into being in the first place and which, in turn, constitutes their everyday practical commitments and the identities of the participants as creative and autonomous individuals" (Kelty, 2005). In this sense, recursive publics are somewhat self-contained, in that they are developed in a manner that allows them to co-exist with other institutions in society that have power, but recursive publics retain their own power, enabling them to more actively dialogue with these entities. Recursive publics draw their power from having agency over their processes, norms and other infrastructural elements. There is a dynamism and flexibility associated with recursive publics which enable them to morph and modulate based on developments that affect them.

Kelty describes Creative Commons (CC) as an example of a recursive public. When it was founded in 2001, Creative Commons was initially focused on creating a set of licenses and an infrastructure to enable creators of copyrightable content to be able to share their works in ways that would encourage reuse, mixing and modification while providing creators with a way for them to be acknowledged for their contributions. As technologies have developed over the years, Creative Commons has observed the application of CC licensing by creators in unanticipated ways, which has prompted the organization and its community to consider whether new mechanisms should be developed to address emerging needs of users that may not be sufficiently met by the original scope of Creative Commons licenses and their goals. Today Creative Commons is a global community with more than 1.4 billion pieces of content using its open licenses (State of the Commons, 2017). This includes music, photos, scientific research, books, art and 3D models.

With the increasing availability of consumer desktop 3D printers, members of the 3D printing community have been using CC licenses to share their digital designs online through sites like Thingiverse, Shapeways and Instructables where individuals can download the digital designs of other users to use them for their own projects. Since the early 2000s, there have been debates about whether the objects produced by 3D printing would be protected by copyright and/or patents (S. M. Santoso & Wicker, 2016; Weinberg, 2013).

Because a wide variety of objects can be digitally designed and 3D printed, there are inevitably objects where aspects of that object are copyrightable but other aspects are not. For example, within a digital design for a vase, the geometric pattern on the vase could be potentially copyrightable and eligible for a design patent as an ornamental design (USPTO, 2018). However, the handle that is part of the vase would be considered functional, and thus would not be copyrightable, but could be eligible for a patent. Creative Commons discovered that many users were applying CC licenses to their digital designs in a blanketed manner without realizing that a CC license would only apply to the aspects of their object designs that were copyrightable. In addition, because the digital designs are eventually 3D printed, one challenge has been to figure out whether there is a way to have CC license and credit attributed to the creator of a design to remain with the object once it has been printed. These are just several of the issues and questions that Creative Commons and its community are addressing as a dynamic recursive public which must address the needs of its members as technological developments take place. 3D printing continues to present multiple challenges to the traditional legal IP system because the functionality of the technology, notably its combination of the digital and physical bring up use cases that do not neatly map to the existing frameworks for patents and copyright.

Another relevant and important recursive public that this research will deal with is the maker community. Kelty articulates that a recursive public is a "group constituted by a shared, profound concern for the technical and legal conditions of possibility for their own association... the people who participate in it will be referred to as "geeks"; and the Internet is the condition of their association" (Kelty, 2005). The notion of the "social imaginary" is used here to describe how members of a recursive public form a shared sense of how they interact and associate with one another. Social imaginaries are neither strictly ideas nor strictly institutions but "ways in which people imagine their social existence, how they fit together with others, how things go on between them and their fellows, the expectations that are normally met, and the deeper normative notions and images that underlie these expectations" (Kelty, 2005). Social imaginaries are dynamic and constantly evolving, allowing one to observe how members conceptualize their social existence through both technical practices and discourse (Kelty, 2005). While Kelty's "recursive public" and his use of "social imaginaries" are valuable for this research, I will use the term maker to describe members of the maker community who self-identify more with this term than "geeks," which Kelty uses as a more generic term to describe individuals actively involved in the development of any recursive public.

As a grass-roots community, the expansion of the maker community over the past 10-15 years has been informed by the several factors. including:

- the development of online platforms and low-cost software that make it possible for individuals to design and share what they have created and connect with other individuals with similar or complementary interests (i.e. Instructables, TinkerCAD, Morphi, Thingiverse);
- the emergence of low-cost and open-source hardware and equipment making it possible for makers to prototype their ideas and reiterate on these prototypes and the growth of makerspaces; and
- shared physical spaces where individuals have shared access to these tools, technology

> and equipment and the opportunity to develop new skills and share knowledge by working together on projects and taking classes (Kalil & Miller, 2014; S. Santoso & Brown, 2015).

When I reference the Maker community as a grass-roots community, I am referring to the way in the community was established and grew from the collective efforts of individuals self-identifying as makers as opposed to large institutions. Makerspaces evolved from hacker culture and hackerspaces, the first of which were created in Europe in the 1980s, such as C-Base (Berlin) and Metalab (Vienna). Hackerspaces were primarily physical spaces where programmers, coders and engineers gathered to work on projects together and were informed by a shared set of values and culture (Callaghan, 2018; Niaros, Kostakis, & Drechsler, 2017). Many of these values were described and defined by Stephen Levy as the Hacker Ethic and included beliefs such as: 1) Access to computers should be unlimited and total; 2) Always yield to the Hands-On Imperative; 3) All information should be free; 4) Mistrust authority–promote decentralization; 5) Hackers should be judged by their hacking; 6) You can create art and beauty on a computer; 7) Computers can change your life for the better (Levy, 2010). Makerspaces share similarities with hackerspaces, but may not fully subscribe to all aspects of the hacker ethic. While makerspaces include programmers, coders and engineers, artists, designers, woodworkers, welders and scientists are also an active part of these communities. It is this intersection where "new technologies," such as microcontrollers, 3D printers and CNC milling machines and "old technologies," such as woodworking equipment and sewing machines can be combined with the arts that innovates upon the original idea of the hackerspace. Central to recursive publics is a commitment to openness in both technical practice and discourse- this openness is integral to the existence of the public. The act of developing open source hardware or openly sharing designs, documentation and projects so that others can fork, modify and build upon them is “essential to freedom and public participation as is speaking to a public about such activities” (Kelty, 2005). Using recursive publics as a lens for analysis provides a way to focus on the topic of technological governance because openness is a main focus. There is a kind of flexibility and modularity associated with recursive publics that create opportunities for members to develop new kinds of interactions and relationships with one another, digital and physical resources. “The social imaginary references the freedom to imagine another world—whether in speech or in code—but it also implies the need to get other people to share this imaginary and to make it the basis of political action” (Kelty, 2005).

3.3 Free Innovation

The development of 3D printing and its democratization has been driven by the actions of users and others who have taken the initiative to identify needs that were not currently being met by the existing technology or creatively thought about the ways in which the functionality and features of the technology could be improved. User-led innovation empowers users to play an active role in the design, re-design and development of a product. This type of innovation posits that engaging with users at all stages of the development of a solution or product is critical, whether during initial prototyping, for refinement and improvement once it is on the market, and in thinking about the ways in which a solution can be built upon, used for another purpose or integrated into something else (Hippel, 2005, 2016). The user in user-led innovation is defined literally, as in the individual or organization that will actively utilize the solution, i.e. the consumer. There are numerous examples of users independently modifying a technology, customizing it in order to fit their specific needs. The mountain bike is a prime example of this (Hippel, 2005; Leadbeater, 2005). The community of avid bicyclists who took their bikes off road made changes and adaptations, such as using larger tires with more traction to make the bikes more suitable for riding through hills and rocky areas (Hippel, 2005; Leadbeater, 2005). Bike manufacturers noticed that there was a demand for bikes with these types of features and eventually incorporated these into a design for a new kind of bike (Hippel, 2005; Leadbeater, 2005). In this situation, there was no formal exchange of IP between users and the bike companies. As a result of the uptake of these ideas by the manufacturers, individuals who may not have had the resources or know-how to modify a regular bike could now purchase a mountain bike (Hippel, 2005; Leadbeater, 2005). However, in considering the community of bicyclists who first had the idea to make these modifications, one could argue that they were not properly compensated for their innovations. Von Hippel's work on free innovation would argue that bike enthusiasts who developed what eventually became known as the mountain bike had alternative motives that did not have to do with making money to begin with (Hippel, 2016). Von Hippel defines a free innovation as "A functionally novel product, service or process that was developed by consumers at private cost (not on paid time) and not protected by its developers (No compensated transactions)" (Hippel, 2016).

User-centered or user-led innovation is distinctively different from producer or manufacturer innovation, which has been the traditional way that companies and firms have sought to develop new products and create additional value for their organizations. User-centered innovation is a main component of what Erik von Hippel describes as the "democratization of innovation" (Hippel, 2005). According to von Hippel, "users are firms or individual consumers that expect to benefit from using a product or a service ” (Hippel, 2005). User-centered innovation has proven to be beneficial to both users and in many cases, the producers, who are experimenting with and developing new models of formally or informally collaborating with users. However, the democratization of innovation is also disruptive to the existing social, legal and organizational infrastructure and processes that have fostered producer innovation for so many years. User-centered innovation empowers users to make changes to a product or service without having to wait for modifications to be made by a firm in order to better address their specific needs. Users may openly share their ideas and their projects with one another, creating a community where users can build off each other’s work.

Free innovations are important because individuals who have a personal use for an innovation will innovate earlier than producers who are more concerned about return on investments (Hippel, 2016). In some cases, free innovations uniquely fill an important need among a group of users that is not being met by the market. The Nightscout project is an example of this. Nightscout was first developed by parents of children with Type 1 Diabetes who wanted to be able to monitor the glucose levels of their children remotely. The Nightscout solution was designed to work with a popular type of glucose monitor, called Dexcom G4. The Nightscout solution was developed as a freely available, open source project. The growing Nightscout community has subsequently developed additional versions of the application that are designed to be interoperable with other glucose monitors and a wider variety of devices (Hippel, 2016). The theoretical concept of free innovation places these activities within an economic, market-based context, which is important in understanding how the market plays a role in accelerating or limiting innovations in 3D printing.

One could also argue that user innovations are more purely driven by their own unmet needs or the needs of others that they know or care about. While a producer may recognize an unmet need, it may take them some time to determine how best to address this need, given their requirements of maximizing the bottom line and/or adhering to the mission of their organization (Hippel, 2016). Von Hippel describes two different modes of free innovation- the first kind involves free innovation by an individual and the second mode consists of free innovation by groups working together. The 3D printing community holds numerous examples of what von Hippel describes as “single free innovators” and “collaborative free innovation projects” (Hippel, 2016). But what happens when individuals who formerly engaged in free innovation pivot to take their free contributions and the contributions of others to capitalize off them? Von Hippel references that free riders will always exist- defined as those who adopt an innovation without paying or contributing to the innovation. A collaborative free innovation project will remain open and continue to exist even if there are free riders as long as the cost of implementing protective measures to exclude such players is greater than the negative impact of these free riders. Yet free riders, the way that von Hippel describes them, in relation to free innovation, is distinctively different than individuals who are initially active participants in a collaborative free innovation project and then shift their actions to financially profit off of the collective work and knowledge generated through the project. One can observe that in this situation, other members of the collaborative free innovation project engage in interventions to either curtail such actions or take steps to self-govern by staging interventions which communicate that such behavior is not aligned with the goals of the project.

An example of this is the evolution of MakerBot, a 3D printing company that was co-founded by Bre Pettis, Adam Mayer, and Zach "Hoeken" Smith. MakerBot, which was launched in 2009, leveraged the developments and technology of RepRap, the first open source 3D printing project. Today, numerous commercial 3D printers using the fuse deposition modeling technique (FDM) can be viewed as being based on the technological breakthroughs of RepRap or inspired by RepRap ("RepRap project," 2019). Other examples include the Prusa, which is a direct off-shoot of the RepRap project, designed by Josef Prusa, one of the original developers for the RepRap and LulzBot, a company based in Colorado that emphasizes its value of open source hardware and software (LulzBot, 2018; Prusa, 2018). When MakerBot launched in 2009, it was considered the first consumer 3D printer on the market. It's first printer, the Cupcake CNC was $900 and sold as a kit. MakerBot's earliest printers, including the Cupcake CNC and its next model, the Thing-O-Matic were open source in hardware and software. During the first two years of the company, MakerBot relied heavily on a passionate and growing user base that created a community, sharing stories about what they'd created with MakerBots, providing the MakerBot team with feedback about its printers and contributing to Thingiverse, a complementary online repository where users could upload the 3D digital design files that they created so others could use them for free. By all accounts, MakerBot was a darling of the open hardware and maker communities because of their resounding commitment to open source and their contributions to the RepRap project, such as developing a tool head that printed pastes (Benchoff, 2016). In August 2012, a Kickstarter project called TangiBot was launched, which publicly marketed itself as "a clone of a very popular open source 3D Printer. It offers the same great performance and features but it costs roughly 2/3 what others will charge you for it" (TangiBot, 2012). The "very popular open source 3D Printer" referred to in the Kickstarter campaign was MakerBot. Just a month after the emergence of TangiBot, MakerBot announced that their newest printer, the Replicator 2, would be closed (Benchoff, 2016). In addition, MakerBot took steps to files several patents, which focused on extruder and build plate components of a 3D printer (Benchoff, 2014a, 2014b, 2016). The backlash from the 3D printing and maker communities was severe (Biggs, 2014; Brown, 2012). Community members accused MakerBot of attempting to patent innovations that were developed and shared online by other individuals on YouTube and Thingiverse (Biggs, 2014; Brown, 2012). At the same time that MakerBot was taking steps to close their technology, other fully open source 3D printer projects and start-ups were entering the commercial market, creating viable alternatives for those committed to using open source 3D printers. This included Prusa i3, a 3D printer that was originally part of the RepRap project. Josef Prusa, the developer of this printer open sourced the plans in 2012 and individuals with the community were selling Prusa i3 kits shortly thereafter. Prusa himself also began selling printers beginning in 2015 through his company, Prusa Research (Prusa, 2018). Similarly, LulzBot, another open source 3D printer, was launched in 2011 (LulzBot, 2018).

In addition, Zach Smith, one of the co-founders of MakerBot, parted ways with the company in April 2012. According to Smith, he was forced out, while others close to MakerBot note that he left of his own volition. What is clear is that Smith has been very public about how the seemingly decreasing importance of open source in favor of intellectual property as a strategy for commercial growth within the company was something he vehemently disagreed with. In an email sent to CNET journalist Rich Brown, Smith reinforced this idea: "The move to closed source was not made because of any real, concrete failing of open source. Instead, it was made as an anticipatory, fearful move. I feel that this is a lack of vision, and a lack of confidence in the very ideals that made MakerBot a great company in the first place ...I truly believe, and have staked my reputation, my career, and my financial security on the idea that the new model of openness and transparency are more competitive than the old model of secrecy and control. I believe MakerBot can be both fully open source and grow at a rate that will satisfy investors and the community alike" (qtd. in Brown, 2012).

Von Hippel describes that there are two diffusion paths for free innovations- 1) free information about a design can be shared directly with peers or 2) design information can flow to producers for free and then be commercialized for further diffusion (Hippel, 2016). He articulates that in certain situations, free innovations may experience a shortfall when it comes to diffusion because of three scenarios- "free innovators may not elect to design an innovation of value to others, free innovators may not elect to invest in development to an extent justified by the total value of the design to themselves and free-riding adopters and free innovators may not elect to invest in actively diffusing innovation-related information to reduce the adoption costs of free riders" (Hippel, 2016). While the theoretical concept of free innovation attempts to quantify and economically describe the kinds of grass-roots innovation that did not initially exist within the domain of industry, there is little reference to how shifting actions of free innovators that are perceived as being counterproductive and exclusive can change the ways in which certain free innovations end up being diffused. Despite MakerBot's movements towards closing what was formerly open source, one could argue that other groups within the 3D printing community continued to develop open source hardware and software, creating their own companies and organizations which sold these technologies but also ensured that these 3D printers would remain open source.

4 CHAPTER 4- Research Design and Methodology

The design and methodology for this research was first and foremost driven by my research questions, which focus on the need to gain a deeper understanding around the motivations of 3D printing users for using Creative Commons licenses, the challenges that they face in this process and existing needs surrounding the sharing of one's digital designs that are currently not being met.

Scholarly research is generally broadly defined across three categories- qualitative, quantitative and mixed methods. Historically, research was identified as either qualitative or quantitative, however, Creswell articulates how "mixed methods has come of age. To include only quantitative and qualitative methods falls short of the major approaches being used today in social and human sciences (Creswell, 2003). As a result, research tends not to fall so clearly in the quantitative or qualitative bucket, but exists on what Newman and Benz propose as the "qualitative-quantitative interactive continuum" (Newman, Benz, & Ridenour, 1998).

Crotty identifies four key questions that are helpful in informing a scholar's research design (Crotty, 1998):

1) What theory of knowledge (epistemology) informs the research? (i.e. objectivism, subjectivism, constructivism)
2) What theoretical perspective lies behind the methodology in question? (i.e. positivism, post-positivism, grounded, interpretivism)
3) What methodology (action plan or approach) will lead to research outcomes? (i.e. ethnography, experiment)

4) What techniques and procedures will be used to operationalize the methodology? (i.e. interviews, surveys, document analysis)

4.1 **Epistemology**

Epistemology can be described as a knowledge claim, philosophical point of view or assumptions which informs how a researcher thinks about the research he/she is undertaking and what he/she will learn. Post-positivism, constructivism and participatory are three different epistemologies. Post-positivism, in contrast to the traditional scientific perspective of positivism, recognizes that when examining the behavior and activities of humans, we cannot be absolutely sure or "positive" of what we consider to be true. In this sense, "postpositivists reflect a need to examine causes that influence outcomes, such as issues examined in experiments" (Creswell, 2003). They believe that observations and analysis can be fallible, creating a need for careful review and iteration of theory.

Constructivism recognizes that individuals are subjective, and it is through this subjectivity that individuals generate meaning about particular situations or experiences. This perspective prioritizes and values the views of the participants and the diversity of points of view, which are then used to create a rich, more holistic narrative about what is happening or taking place when it comes to a particular phenomenon. Schultz articulates that "a research method might be classified as constructivist or social constructionist to the extent that it (a) elucidates `local' as opposed to `universal' meanings and practices, (b) focuses upon provisional rather than `essential' patterns of meaning construction, (c) considers knowledge to be the production of social and personal processes of meaning-making, and (d) is more concerned with the viability or pragmatic utility of its application than with its validity per se (Neimeyer & Levitt, 2001). Open-ended questions are a key aspect of enabling a socially constructed epistemology, allowing participants to more freely share their thoughts. A researcher who approaches his/her work from a constructivist standpoint reflexively recognizes his/her own subjectivity and how his/her interpretation of the data and information collected and research findings are directly affected by his/her values, experiences, culture, and so forth. This approach places an emphasis on context.

The participatory approach is one in which the researcher brings a perspective of advocacy and agenda on behalf of the individuals that he/she is studying. In this situation, research is interwoven with politics, with the goal of providing a particular disenfranchised group a voice- empowerment, inequality, oppression, domination, suppression, and alienation are often issues that are areas of focus for researchers taking this particular philosophical view. Kemmis and Wilkerson discuss how a participatory stance concentrates on bringing about change, with this research being a collaborative process between a researcher or researchers and a particular group as opposed to a researcher observing from a distance (Kemmis & Wilkinson, 2002) (1998). Here, the scholar is somewhat embedded in the participant group, working alongside these individuals.

I will be taking a constructivist approach for this research. I believe this epistemological standpoint will provide the opportunity to more holistically understand the experiences of the heterogeneous 3D printing community in relation to their application of the technology and how they go about designing, sharing and distributing what they've created. Because constructivism is contextual, it will also enable me to recognize and take into account the contextual nuances of specific cases and applications of 3D printing. As a member of the 3D printing and maker communities, I will also leverage the constructivist point of view to be reflective about how my own experiences inform my research, observation and analysis.

4.2 Quantitative, Qualitative and Mixed Methods Research

My research was qualitative in nature and I used interviews as my main research method. In determining the nature and method of my research, I considered quantitative, qualitative and mixed methods approaches and believed that qualitative research provided the rich data and information necessary to address my research questions.

There are various approaches to engaging in quantitative research. Two main types of quantitative research include experiments and surveys. Quantitative research can broadly be defined as research which collects data that can be assigned numerical values and can be quantified. Experiments include randomized and non-randomized designs during which subjects are exposed to treatment conditions or serve as part of the control group. “Surveys can consist of cross-sectional and longitudinal studies using questionnaires or structured interviews for data collection, with the intent of generalizing from a sample to a population” (Babbie, 1990 qtd in Creswell, 2003). Surveys are ideal when a researcher wants to use close-ended questions to collect data in a standardized, quantifiable form. If well designed, with a large enough and appropriately sampled set of survey participants, a survey can provide an overview or snapshot of what is happening at a particular time, with findings that could be generalizable to a larger population.

Researchers can use different strategies to undertake qualitative research ranging from ethnography, grounded theory, case studies, phenomenological research and narrative research. "Qualitative research is characterized by an interpretative paradigm, which emphasizes subjective experiences and the meanings they have for an individual. Therefore, the subjective views of a researcher on a particular situation play a vital part in the study results" (Starman, 2013). Kirk and Miller articulate that qualitative research "involves sustained interaction with the people being studied in their own language, on their own turf" (Kirk & Miller, 1986).

My approach to this research was qualitative and inductive and used grounded theory. "Grounded theory refers to a set of systematic inductive methods for conducting qualitative research aimed toward theory development. The term grounded theory denotes dual referents: (a) a method consisting of flexible methodological strategies and (b) the products of this type of inquiry. Increasingly, researchers use the term to mean the methods of inquiry for collecting and, in particular, analyzing data" (Charmaz, 2003). Grounded theory is conducive to understanding social relationships, processes and behaviors of groups through an iterative process that involves the collection and analysis of data, drawing conclusions and using these learnings and insights to collect additional data, conduct subsequent analysis and gradually develop theory for the work itself (Strauss & Corbin, 1990). "Two primary characteristics of this design are the constant comparison of data with emerging categories and theoretical sampling of different groups to maximize the similarities and the differences of information" (Creswell, 2003).

Glaser and Strauss, in their seminal book, define grounded theory as "the discovery of theory from data systematically obtained from social research" (Glaser & Strauss, 1967). "Theory in sociology is a strategy for handling data 'in research, providing modes of conceptualization for describing and explaining” (Glaser & Strauss, 1967). Grounded theory focuses on being generative, as opposed to the traditional scientific research approach of verifying a theory or confirming or negating a hypothesis.

My research consisted of two phases. The first phase focused on a series of 20 open-ended interviews with various members of the 3D printing community, with a concentration on 3D printing users. Members of the 3D printing community also included 3D designers, printer manufacturers and other entrepreneurs or project creators working with 3D printing. In many cases, a 3D printing user could also occupy more than one role in the community, for example, when a 3D printing user designed his/her own 3D files. Individuals who used 3D printing may also have used a variety of other technologies for their projects such as welding equipment, computer numerically controlled milling machines and laser cutters.

Interviews from this first phase were used to develop a nuanced understanding of the ways in which users and key stakeholders within the 3D printing community are experiencing and engaging in the sharing of digital design files, the role of Creative Commons and traditional forms of IP (e.g., patent, copyright) in this process and key challenges and issues that have emerged in these processes. A combination of purposive and snowball sampling was used to identify interview participants. The reasoning for using these sampling methods is discussed in further detail in the subsequent section. Interviews were conducted in batches, allowing me to speak to several participants, analyze and code interview transcripts and identify key themes or particular topics that required additional investigation. A grounded theory approach was employed throughout this process.

These initial interviews were then used to determine several key cases studies that provided additional insights, detail and depth in understanding critical examples related to the phenomena at hand. Case studies, in which the researcher explores in depth a program, an event, an activity, a process, or one or more individuals. A case study "explores a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information" (Creswell, 2003). Three distinctive types of case studies are described by Stake, each of which serve a different purpose during the course of research. The intrinsic case is used to understand the particulars of a single case, rather than what it represents. An instrumental case study provides insight on an issue or is used to refine theory. The case is selected to advance understanding of the object of interest. A collective refers to an instrumental case which is studied as multiple, nested cases, observed in unison, parallel, or sequential order (Hyett, Kenny, & Dickson-Swift, 2014).

4.3 **Sampling**

The sampling method(s) that a researcher chooses to utilize should be driven by the main goals for the research in question (Higginbottom, 2004; Koerber & McMichael, 2007). Because of the nature of qualitative research, sample size tends to be small compared to quantitative research. Tuckett articulates that qualitative data collection is iterative by nature and should be interwoven with the ongoing process of analysis (Tuckett, 2004). Key qualitative sampling techniques are quota, purposive and snowball. Ultimately, I chose to use a combination of purposive and snowball sampling.

Purposive sampling centers around the identification of study subjects based on specific traits, characteristics or knowledge that a researcher is looking for. There are several different types of purposive sampling which yield different participants: maximum variation sample, deviant sample, critical case sample and key informant sample (Marshall, 1996). My purposive sampling will seek to achieve a certain level of heterogeneity across critical factors including 3D printing application, level of mastery and role within the community and will strive to identify individuals who can provide important insights into what is actually taking place. "Rather than choose respondents randomly, and thus risk unwanted duplication in our sample, we may prefer to select respondents purposively so that we obtain instances of all the important dissimilar forms in the larger population" (Weiss, 1994).

Snowball sampling is an approach that involves the researcher engaging a current research participant in identifying or referring additional participants. Snowball sampling is often used when studying groups that are hidden, obscure or otherwise difficult to directly engage with. Although I am familiar with a number of members from the 3D printing community, to minimize bias, I want to ensure that I am not interviewing someone that I have an existing relationship with unless it is because of their specific knowledge or expertise in some aspect of the research that I am conducting. Critics of snowball sampling assert that community bias can be a critical disadvantage to this form of sampling- the idea that the initial participants can have a significant impact in determining who else participates in the study moving forward. However, because the 3D printing community is diverse in how members are using the technology, participants are helpful in identifying participants that are using the technology for a wide variety of purposes, in fields and industries that I might not have contact with. Snowball sampling will also help me to reach individuals who are not active users of Creative Commons and thus, whose activities may not be as visible online, but who could be valuable interviewees.

4.4 **Secondary Data**

While a significant portion of the data collected for this research with be primary through interviews, this research will also involve the gathering of secondary data that are "naturally occurring texts," which include articles, blog posts, online comments and other texts self-generated by the 3D printing community. In selecting which documents to focus on, Fairclough articulates the importance of quality over quantity (Fairclough, 2003). Examples of such secondary data include notes from a workshop hosted by Creative Commons which brought together 3D printing community members to talk about their experiences using CC licenses and an Instructables post by XYZ Workshop outlining why it chose to open source its design for a 3D printed dress. Fairclough provides some insights into how texts should be part of the meaning-making process, but examined within the social, political and power structures in which they are created: "...one needs to look at interpretations of texts as well as texts themselves, and more generally at how texts practically figure in particular areas of social life, which suggests that textual analysis is best framed within ethnography. To assess the causal and ideological effects of texts, one would need to frame textual analysis within, for example, organizational analysis, and link the 'micro' analysis of texts to 'macro' analysis of how power relations work across networks of practice and structures. Textual analysis is a valuable supplement to social research, not a replacement for other forms of social research and analysis" (Fairclough, 2003).

4.5 **Reliability & Validity**

Reliability and validity are critical factors that I sought to maximize in the design and methodology of my research. Validity can be defined as how well measures actually measure what they intend to measure (Kirk & Miller, 1986; Schutt, 2006). A measure should not measure something in addition to what it is supposed to measure, meaning that a valid measure would seek to minimize confounding factors by measuring just the phenomena at hand. Lincoln and Guba also describe validity as “truth value” or the truth of the findings of a particular inquiry for the subjects with which and with context in which the inquiry was carried out (Lincoln & Guba, 1985). Reliability is the extent to which a measurement yields the same answer consistently (Kirk & Miller, 1986). Validity and reliability are generally viewed as being two related and critical components of maintaining objectivity in qualitative research. It is possible for a measure to be reliable but not valid or valid but not reliable. In other words, reliability and validity are not symmetrical (Kirk & Miller, 1986). It is necessary to discuss the importance of minimizing bias and error as these factors also impact validity and reliability. Three kinds of error and bias are reactive effects (influence from the observer’s research role or observer’s presence), perceptual and interpretative distortions (errors related to the observer’s personal characteristics) and sampling errors (limitations of sampling due to theoretical perspective, observer’s characteristics). For this research, I employed triangulation and member checking as two techniques for minimizing bias and maximizing validity and reliability. Triangulation involves the use of multiple data sources or methods to develop a holistic understanding of the activities being studied. My approach to triangulation focused on drawing from different data sources to ensure that the primary and secondary data and information I gathered and analyzed captured a breadth of different and critical viewpoints as they evolved over time (Lofland, Snow, Anderson,

& Lofland, 2006). Member checking was used to provide interviewees with the opportunity to correct any errors or misstatements that I may have made in the process of taking notes and summarizing what interviewees have shared with me. The process of member checking during my research took place both during the interview process and in some cases during the analysis process, when additional clarification or confirmation was needed (Lofland et al., 2006).

5 CHAPTER 5- Interview Analysis

While the original goals of this research focused more specifically on the IP issues facing 3D printing users, the overall findings of these activities actually provide broader insights around how users of a particular technology, in this particular case, 3D printing, engage in different kinds of practices around sharing what they have created (digital design files) and the ways that these behaviors create an active community committed to perpetuating the creation of new knowledge, solutions and objects. While this research started out with very focused questions about one very specific kind of sharing (the use of CC licenses, what drives this use, challenges around this use, etc.), the research and findings ended up being more about how the broader practices of sharing digital design files are informed by the existing values and experiences of the individuals involved, field-specific issues and existing power structures, institutions and hierarchies that can enable or challenge this kind of work.

Because 3D printing is utilized in a wide range of fields and sectors (e.g., education, fashion, healthcare, engineering, humanitarian, transportation), it was important to interview individuals working with this technology in different areas and for various purposes. An individual's perspective, approach and behavior around the 3D design, sharing and distribution of something he/she has created is informed by his/her own personal experiences and motivations and the norms, incentives and systems of the field that he/she is working within.

Recall that this dissertation research focused on the need to gain a deeper understanding around the motivations of 3D printing users for using Creative Commons licenses, the challenges that they face in this process and existing needs surrounding the sharing of one's digital designs that are currently not being met. Along the way, this research also explores how 3D printing is a technology that has developed and evolved as the result of new groups having the opportunity to participate in the design and co-construction of the technology and the development of its applications. It looks at the ways in which the expansion of 3D printing has created tensions and questions with regards to the ways in which this technology can and should be governed by the existing IP legal infrastructure. This includes a deeper understanding of the ways in which individual 3D printing users think about their creations in terms of intellectual property and how this is demonstrated in the actions they take as they actively push their creations out into the world or take steps in the other direction to protect what they have created. Finally, it examines the unique complexities that arise when 3D printing is applied to specific fields that have not previously utilized this technology and the ways in which users, organizations and institutions are negotiating with issues that include IP, safety and accountability.

The 20 semi-structured, open-ended, exploratory interviews conducted provided critical insights which shed light on the decision-making process that 3D printing users go through before choosing to share what they've developed. This process is complex, involves many different factors and is context specific. Once the decision is made to share an artifact, a user must consider the technical aspects of sharing- what platform to use, what information to include with a design file, the risks and opportunities involved. In some communities and fields, sharing is also considered a contribution in support of the community, is tied to the identity of the individual and for those who feel strongly about open source, an act of social activism. Individuals who design the hardware or 3D printers themselves also go through a similar process, although the critical questions of the sharing of hardware blueprints and documentation are distinctively different than those related to digital design files of 3D printable objects. The interview guide (Appendix 9.3) I used in each interview maps directly to the research questions I set out to address in this dissertation:

- Why do 3D printing users choose to use Creative Commons for their digital design files?
- To what extent do 3D printing users understand Creative Commons, how licenses can be used and what they provide?
- What challenges do 3D printing users have when it comes to using Creative Commons for digital design files?
- What technical mechanisms and other features could be used to address these challenges?

Interviewees came from a broad range of fields and had various relationships to 3D printing. These individuals worked in healthcare, education, academia (english, entrepreneurship, mechanical engineering), aerospace, humanitarian aid, environmental conservation, biochemistry and architecture. With the exception of one person, each individual's relationship to 3D printing embodied that of a 3D printing user and one or more of the following roles: 3D modeler, 3D printer designer/manufacturer, 3D tools developer, 3D printing educator.

Table 1: Expert roles within the 3D printing community

Role	**Description**
3D Modeler	One who uses 3D modeling software to create 3D digital designs or modify existing 3D digital designs.
3D Printing User	One who uses a 3D printer to produce physical objects from 3D digital designs. A 3D printing user might print objects designed by

	others or objects that he/she designed.
3D Printer Designer/Manufacturer	One who has designed and produced his/her own 3D printer for his/her own personal use or manufactured more broadly for use by others. Assembling a 3D printer from an existing kit that he/she did not create does not constitute being a 3D printer designer/manufacturer.
3D Tools Developer	One who is involved in the development of tools, software or other technology which expands the capability of 3D printing through improvements to the 3D scanning process, improving the usability of 3D modeling software or platforms that facilitate sharing of 3D digital designs for example.
3D Printing Educator	One who teaches other individuals how 3D printing works and makes it possible for others to be able to use a 3D printer.

Table 2: Overview of Interviewees

INTERVIEWEE (names used here have been changed for the purposes of anonymization	FIELD/DOMAIN	RELATIONSHIP TO 3D PRINTING
1 – Jane	humanitarian/ international development	3D modeler, 3D printing user, 3D printing educator
2 – Nick	humanitarian/ international development	3D printing educator, 3D printing user

3- Elena	humanitarian/ international development	3D printer designer/manufacturer, 3D printing user, 3D printing educator, 3D modeler
4- Ben	education	3D modeler, 3D printing user, 3D printing educator
5- Gus	education	3D modeler, 3D printing user, 3D printing educator
6- Cara	academia (English) / GLAM (galleries, libraries, archives, and museums)	3D modeler, 3D printing user, 3D printing educator, 3D printing user
7- Violet	biochemistry	3D modeler, 3D printing user
8- Nan	architecture	3D printing educator, 3D printing user
9- Ted	academia (Business)	3D printing educator, 3D printing user
10- Kevin	GLAM (galleries, libraries, archives, and museums)	3D modeler, 3D printing user, 3D tools developer
11- Carl	academia (Humanities) /	3D modeler, 3D printing user

	GLAM (galleries, libraries, archives, and museums)	
12- Kate	product design (assistive technologies)	3D modeler, 3D printing user, 3D printing educator
13- Matt	art, large scale interactive displays, carpentry	No use of 3D printing, but heavily engaged with others who use the technology
14- Greg	hardware, technology	3D modeler, 3D printer designer/manufacturer
15- Kurt	education	3D modeling, 3D printing user, 3D printing educator
16- James	unmanned aerial vehicles/drones	3D modeling, 3D printing user
17- Scott	environmental conservation	3D modeler, 3D printing user, 3D printing educator
18- George	ocean conservation	3D modeling, 3D printing user, 3D printing educator
19- Addie	entrepreneurship	3D printing user, 3D printing educator

20- Peter	aerospace	3D modeler, 3D printing user

First, I will describe the findings from the interviews which correspond directly to the original research questions in this dissertation.

Why do 3D printing users choose to use Creative Commons for their digital design files?

Of the 20 interviewees, 7 individuals, or one-third had previous experience using Creative Commons to share a digital design file that they had developed. This was a much smaller proportion of interviewees than I had originally expected. This included 1 educator, 2 humanitarians, 1 entrepreneur, 1 drone designer, 1 ocean conservationist and 1 hardware designer. All individuals in this group expressed that when they choose to share the design of a device, artifact or object, it is because they believe what they've created will be useful to the broader community of 3D printing users. One aspect that all interviewees agreed upon was that the decision to use Creative Commons licenses was made easier by the fact that the licenses were already integrated into the uploading process on the platform that they were using to host their design files- Thingiverse. For those individuals who were designing devices that sought to solve a large-scale problem, such as the need for widespread water quality monitoring, the ability to use CC licenses to share a 3D printable solution is viewed as a part of the process of putting a particular technological solution into the hands of more individuals who by working together, have a better chance of solving a big problem.

To what extent do 3D printing users understand Creative Commons, how licenses can be used and what they provide?

There is a basic level of understanding about Creative Commons and how these licenses can be used, but a confusion around what they cover and how effective they really are. Three of the interviewees which used CC licenses expressed doubt that the licenses completely covered their designs, given that CC licenses were designed to cover copyrightable content. But given that the digital designs are for physical, 3D objects that are utilitarian and are designed to perform certain functions, these individuals wondered whether it was also necessary for them to secure a patent equivalent to Creative Commons licenses. There is a patentleft movement which is focused on the practice of licensing patents for royalty-free use, on the condition that adopters license related improvements they develop under the same terms (P2P Foundation, 2011). Creative Commons has also created the CC Public Patent License, which is designed to be used as part of a public license offer to enable the public to broadly use a patent (Creative Commons, 2010). However, copyleft and the CC Public Patent License were not referenced by the interviewees and have not been used by these individuals.

What challenges do 3D printing users have when it comes to using Creative Commons for digital design files?

In addition to the uncertainty of whether a Creative Commons license protects just the design, or the actual physical object created from the design, interviewees who are using Creative Commons and those who have chosen not to use Creative Commons acknowledge the limitations of enforcing the licenses. There is currently no way for the creator of a digital design file to monitor how a file is being used by others after it has been shared online and whether these applications are aligned with the particular usage guidelines specified by the license.

Interviewees indicated that while a license can act as a suggestion as to how an individual should use a design file, there is a limited amount of recourse that can take place if another user is found to have misused a file. This is particularly the case if the other user is a larger company or organization which has significantly more legal resources than an individual designer. It is important to emphasize here that this challenge is not exclusive to Creative Commons but is an issue that is faced by copyright holders in general who are faced with the burden of policing the misuse of their content by others (Campidoglio, Frattolillo, & Landolfi, 2009; Neville-Rolfe, 2016).

What technical mechanisms and other features could be used to address these challenges?

Based on interviews with individuals who are using CC licenses and those who are not using licenses, it is clear that resources that provide 3D printing users with basic information about how Creative Commons licenses apply to 3D digital designs and the limitations of these licenses would be helpful. It is not enough to provide this information, but it would be important to place this within the context of other options that individuals have to protect and share their works, including traditional copyright protection, complete open-sourcing and deciding not to share a design file altogether. Whether individuals used Creative Commons licenses or not, when sharing their digital designs, interviewees expressed the need for a technical mechanism that would enable them to understand how other users are leveraging their designs.

5.1 Valuable but unexpected insights regarding the sharing of digital designs and other 3D printing innovations

Collectively, these in-person and remote interviews provided valuable insights, a number of which were unexpected findings about the use of Creative Commons and the sharing of digital designs and other 3D printing innovations. While the research questions of my dissertation and the questions of my interview guide focused specifically on the use of Creative Commons by members of the 3D printing community, I discovered that only a small proportion of individuals I spoke with (7 out of 20), had experience using Creative Commons licenses for the digital designs that they had developed. In these cases, individuals were far less engaged and informed about the functionality of Creative Commons than I had originally expected. When these individuals used CC licenses to share their digital designs, it was often done out of convenience because the online platform provided it as an option that they could select as they went through the process of uploading their design files. These 3D printing users found it difficult to recall the kinds of CC licenses they used for particular digital designs and indicated that while they believed that these licenses provided guidance for how others should use their designs, they also acknowledged that in reality, the licenses were minimally effective because as the creators, they had no real way of monitoring whether others had been following these guidelines.

I had anticipated that the use of CC licenses would be tied to a strong identification with the Creative Commons ethos and being part of the Creative Commons community, but this was not the case. Those who used CC licenses did have strongly held beliefs about the importance of sharing their digital designs as a form of contributing to a repository of shared knowledge, but it was not directly tied to Creative Commons. Instead, this perspective on the need to share was informed by personal beliefs developed through experience and/or the culture of a group to which that individual belonged.

While Creative Commons was used much less than I had anticipated, I also discovered that the ways that interviewees choose to disseminate their digital designs and other 3D printing related innovations is more heterogeneous than I had expected. Individuals sharing 3D printing hardware plans and documentation use different platforms to share their work and use different licenses. Within the specific area of digital design files, the diversity in approaches to sharing also stems from the different IP issues that individuals face which are intertwined with the application that they are using the technology for. In other words, while there are IP issues shared across the creation of digital design files, there are other IP questions which arise that are intertwined with the context-specific application of the technology. This is explored in further detail across the three case studies that have been developed as part of this dissertation.

While every interviewee did not have an experience using Creative Commons or a particularly strong understanding or perspective on the value of the licenses or the significance of the community developed around this alternative to traditional copyright enforcement, every individual I spoke with did have well developed thoughts about how their sharing activities were informed by their own personal values, the practices and norms within the fields that they work in and previous experiences with the legal system IP system, including working with trademarks, patents and copyrights. Thus, the findings detailed in this interview analysis extend beyond the responses to the set of questions initially specified in the interview guide. These are distilled into a set of key observations about: 1) the critical factors which inform the conditions for using

Creative Commons; 2) the sharing of digital files and information about 3D printing hardware; 3) the challenges and questions that arise once the decision to share an artifact has been made; 4) the ways that applications of 3D printing to specific fields create risks and uncertainties; 5) how these new risks and uncertainties can be resolved through new norms and policies; 6) how users are leveraging 3D printing to tackle a specific long-term problem in a field; and 7) the ways in which shared 3D digital designs might be utilized beyond 3D printing.

These practices of sharing and distributing valuable knowledge that others can use or modify is a critical part of the innovation process. Differences in how this knowledge is shared, how users can gain access to this and the ways in which this knowledge is tied to commercial markets describes three different types of innovation. Von Hippel differentiates "free innovation by single individuals in the household sector of the economy, collaborative free innovation by multiple household sector participants and innovation by producers" (Hippel, 2016). Those who engage in free innovation share what they create freely and enable others to use what they have created without monetary or other cost. Producers are companies, organizations or individuals that are focused on innovating on technology or artifact because of its potential commercial value- they are interested in the ability to sell the innovation to a broader set of consumers. Below are the analytical findings from the interviews.

5.2 Critical factors which inform the sharing of digital files and 3D printing hardware

Personal previous experiences inform a user's perspective on the value and importance of sharing. Creative Commons can be used to enable this sharing. An individual's general perspectives around sharing digital design files and designs and documentation for 3D printing hardware are significantly affected by their previous experiences with sharing other types of artifacts, having used content made available by other users or having directly dealt with the traditional intellectual property system of trademarks, copyrights and patents in some way.

*George is a deep-sea ecologist and conservation technologist with a background in civil engineering. Leveraging his background in computer-aided design (CAD) modeling in his previous work as a civil engineer, George has utilized 3D modeling and 3D printing to develop a series of low-cost tools and hardware to enable individuals to collect data about the ocean (George, 2019). This includes Open CTD, an open source instrument for measuring salinity, temperature, and depth in the ocean and Niskin 3D, a 3D-printable, open-source water sampler (Oceanography For Everyone, 2019). These tools contain some 3D printed components, along with other parts and hardware. George's philosophy around the tools that he creates is in his words "open source and open access- ride or die" (George, 2019). This is informed by his philosophy that as a scientist, he is focused on collecting data to be shared with the world and empowering other individuals and citizen scientists, to be able to build upon his efforts through the use of the hardware and tools that he has developed. Because of George's belief that the devices he develops should be widely shared, George uses a combination of different licenses in distributing the digital design files, source code and documentation for these tools. This includes the use of the MIT license, a type of non-restrictive open source software license that he utilizes for the source code he makes available through GitHub and the Creative Commons-Attribution and Creative Commons - Attribution - Non-Commercial license for the digital design files (Oceanography For Everyone, 2019).

An opposing perspective was shared by *Scott, a mechanical engineer focused on the design and development of tools for environmental conservation. Scott has taken a more cautious approach to sharing the solutions that he and his team have developed with a broader audience. One main reason is the uncertainty of not knowing exactly how individuals will use what is shared and the concern that someone could misuse a digital design file or commercialize the design (Scott, 2019). While George is not interested in commercializing the tools that he's developed or in his words, "becoming a manufacturer," Scott articulates that a number of projects he is working on are solutions that he believes he and his team would have an interest in commercializing (Scott, 2019). Scott's thoughts around sharing are nuanced and are directly intertwined with the recognition of the value of the IP that he creates in the process of designing these tools, the commercial potential of these solutions and his desire to capitalize on these opportunities himself.

*Kevin works for the Smithsonian, a U.S. federal agency focused on the preservation of historical and cultural artifacts. These artifacts are part of the collections of the different Smithsonian museums such as the Museum of Natural History or the Air and Space Museum. As part of this work, Kevin and his team have developed a system for digitizing the artifacts in 3D. In some cases the digital models of these artifacts are publicly shared for educational purposes through an on online platform, Smithsonian 3D (Kevin, 2018). Some of these models can be freely downloaded by the public from the site, while other artifacts might be viewable on the platform but cannot be downloaded. Other artifacts are digitized but not shared online with the public. There are various factors which play a role in determining whether an object will be shared. This includes the extent to which an object is a culturally sensitive item, meaning that it could be sacred to a particular group of individuals.

Another interviewee, Ben*, a science teacher, credited the first open-source digital design file for a hand prosthetic with getting him involved in 3D printing and changing the trajectory of both his teaching career and family life. This 3D printed prosthetic was initially designed by Ivan Owen (a designer) and Richard Van As (an engineer) for Liam, a young boy who was born with Amniotic Band Syndrome (ABS), which left him with no fingers on one hand. Ben's son also had ABS and upon stumbling across a video online about Ivan and Richard's work, Ben realized that this low-cost prosthetic could be something that could help his son (MakerBot, 2013). 3D printing could be a technology that he could use to engage his students in science, engineering and real-world problem solving. Ben notes, "I had a pivot in my professional life where I realized, here is a technology with which kids can create high quality and professional grade solutions to problems." Ben's very first project involving 3D printing was working with a group of twelve students to modify the open source digital design prosthetic file to print a customized prosthetic for his son. This experience of seeing how the simple act of someone sharing something useful that they created with 3D printing significantly informs how Ben chooses to share what he's created.

In this context, one can observe how one instance of free innovation can serve as a catalyst for other free innovations. In other words, being a beneficiary of free innovation previously correlates with interviewees engaging in free innovation in the future. The collaboration between Van As and Owen to design a low-cost, customized 3D printed prosthetic for Liam was a free innovation because it was "a functionally novel product, service, or process that (1) was developed by consumers at private cost during their unpaid discretionary time (that is, no one paid them to do it) and (2) is not protected by its developers and so is potentially acquirable by anyone without payment- for free" (Hippel, 2016). Van As and Owen shared the digital designs for this prosthetic on Thingiverse, the largest online platform of freely available designs for 3D printing (MakerBot, 2013). The 3D printable digital design for a low-cost prosthetic was distributed through free, peer-to-peer diffusion through the Internet- more specifically, social media, YouTube and Thingiverse. Like the parents who co-founded Nightscout, Ben was motivated to become an early participant and contributor to developing and improving upon low-cost 3D printed prosthetics because of the personal need for this innovation (Hippel, 2016).

"Universality" has become a criteria which Ben uses in determining whether something should be more widely shared. Ben developed a site for the school where he teaches that allows parents, staff, teachers and community members to post problems that students can solve by designing a solution that can be 3D modeled and printed ("Brookwood's 3D Design Problem Bank Project," 2019). While the solutions that he works with students to develop are useful, in many instances they are so specific to a particular situation that the chances of a design file being applicable to another situation are slim or the design file would require so much customization that it could be easier for someone to simply design something from scratch. Ben articulated that he shares digital designs of the things that he identifies as having met the criteria of universality- something that others demonstrate a need or demand for and where the modification of the file is still easier than creating something completely new. An example of such an object is a teaching tool that Ben developed called the Grab-Tor, which allows elementary and middle school students to better understand how the mechanics and engineering behind the 3D printed hand prosthetics function. He created this after hearing from other teachers that they wished there was an easier way for their students to engage in a more active and deeper design experience to scaffold around 3D printing and constructing the prosthetic hands. The Grab-Tor was uploaded to Thingiverse and made available for others to use under the CC Attribution Share Alike license (Thingiverse.com, 2017).

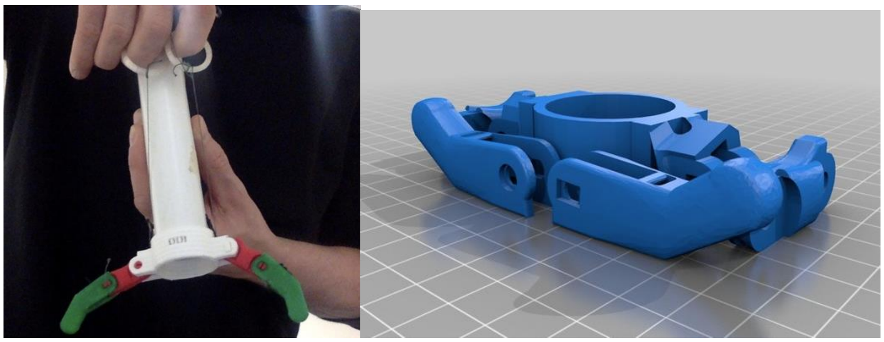

Figure 1: Grab-Tor device for teaching students about prosthetics (Source: Thingiverse)

Hippel articulates, “there is a sequence of three choices made by developers of free innovations that can each and collectively result in systematic diffusion shortfalls within the free innovation paradigm. First, free innovators may not elect to design an innovation of value to others. Second, even if a design does have general value, free innovators may not elect to invest in development to an extent justified by the total value of the design to themselves and free-riding adopters. Third, free innovators may not elect to invest in actively diffusing innovation-related information to reduce the adoption costs of free riders.” (Hippel, 2016). In Ben’s case, his criteria of universality embodies this second observation- that a design must have general value before he considers whether or not to more broadly share it and that even when such value has been demonstrated, the effort of assembling the design and documentation and uploading it online so others have access must be outweighed by the value to the public. Thus, “free innovators’ efforts to diffuse information about their innovations to producers are significantly related to their assessment of the general value of the innovations” (Hippel, 2016).

Similarly, *Kurt, an instructional facilitator for technology at a large public school district with 90,000 students, had been in search of new approaches leveraging technology that he could introduce to help his fellow teachers engage students in more interactive and meaningful learning experiences. For several years, his district had been talking about the ways that the 1 to 1 model, in which every student would have an electronic device such as a laptop or tablet to access the Internet, digital text books and other educational resources would have a significant impact on the quality of education for their students. Kurt did not feel that there were real results with the 1 to 1 model. In 2013, after learning that a Printrbot 3D printer could be purchased for $500 (which he pointed out was less than a graduate school course), Kurt decided to in his words, “invest in this new tech as a catalyst for change” and began to explore how making, makerspaces and digital fabrication fit into the classroom (Kurt, 2019). At the same time that Kurt purchased his first 3D printer, he made a commitment to share his experience with other educators through Twitter, Instagram and a blog he created (Kurt, 2019). As part of this broader effort, Kurt also shares the digital design files for a significant number of the educational projects he develops. As someone who works with teachers to integrate technology into their teaching practice, Kurt’s district adopted an initiative called “one to the world,” where students were tasked with developing solutions to local and global problems. From Kurt’s perspective, this connected with his own belief that students should learn to build upon and contribute to existing knowledge. Thus, encouraging the students he was working with to document and publicly share what they developed was a critical part of this process. “For me, as far as doing the blog and publishing, and spending my own money to do these things, I’ve received far more reward from that process than I have from trying to sell a lesson plan to other teachers” (Kurt, 2019).

Another interviewee, *Kate, asserted that her philosophical belief in the importance of transparency when it comes to sharing information about projects directly informed her work with the non-profit organization she helped to create which focuses on the development of low-cost assistive technologies. These technologies use a variety of materials and technologies, including 3D printing (Kate, 2019). Solutions developed as part of the programs created by Kate's organization are licensed under Creative Commons.

*James is a designer and engineer for custom unmanned aerial vehicles (UAVs) or drones. What originally started out as a hobby became a full time profession when James saw a need and demand for drones that focused on both design and aesthetics at the same time as functionality and performance (James, 2019). While James has established a profitable business designing and manufacturing drones, he also widely shares certain parts of his drone designs online for others to use and modify and views this as a way of contributing back to the drone enthusiast community (James, 2019). The parts he primarily shares include designs for canopies and pods which hold, cover and protect the electronic components of these devices. However, James recognizes that there are specific aspects of the drones he designs that contain valuable IP which are critical to the viability of his business. This IP is focused on the composition of the carbon fiber that is used to create many of the components of the drones and from James' perspective serves as the basis of the products that they sell. For James, his decision to share the 3D digital designs for the canopies and pods is based on his thinking that these designs could be helpful to other individuals using 3D printing to create their own drones and that these designs are not financially critical to James' business (James, 2019).

5.3 Challenges and questions that arise once the decision to share something has been made

Determining format and distribution method. When an individual decides to share an artifact that they've created, whether this is a digital design file or documentation for a 3D printer, he/she must first decide the format and method of distribution by which he/she will share this asset with others. The individual may also decide whether to release the artifact with a Creative Commons license.

Online repositories such as Thingiverse have features built in which make it possible for creators of digital design files to select a Creative Commons license upon uploading a file, but in some cases users might choose to share a file on their own site or through a more vetted process. An example of a more vetted process is requiring another user to email the creator of a digital design file directly to request access. The creator may ask the user to specify what they plan to use the file for and additional information about the user's skills and background in 3D printing. When it comes to sharing information about 3D printing hardware, there is no one central location where all blueprints, documentation and source code resides online, so 3D printing designers and manufacturers must decide where to make these assets available.

For George, decisions about how to share the source code, digital design files and additional documentation for the low-cost tools he has developed are driven by the goal of maximizing access and use of these devices. As part of the preparations for sharing the projects more broadly, George spends a significant amount of time on the documentation for each project- this includes materials such as a full construction and operation manual for a specific device, so that individual users have a deep understanding of how the tool functions, its possible applications and how it could be modified (George, 2019). George estimates that he spends as much, if not more time on writing and assembling the documentation for a project as he does developing the actual tool or hardware itself (George, 2019). From his perspective, this documentation can make a significant difference in terms of the extent to which individuals will utilize but also extend the functionality of these devices by modifying and building upon what George has developed.

There are two platforms where George uploads the content for his hardware- GitHub and Thingiverse. GitHub is used as a central repository where all elements of the project are housed, including the digital design files for the 3D printed parts of the devices. George utilizes Thingiverse as a secondary platform where he also makes the digital designs files available. George leverages both platforms because although there may be some overlap, each site has its own distinctive community of users who could potentially be interested in these projects.

When James first began sharing the 3D digital designs for the canopies and pods that he created to house the electronic parts for drones, he initially posted these files and documentation to his own website. However, he found these initial attempts to put the files on his site cumbersome and hard to manage (James, 2019; Thingiverse.com, 2019b). He found a more streamlined approach was to post the files and documentation to Thingiverse, but because of the iterative nature of his design process, the final versions of a design don't always end up there due to time constraints and other competing priorities. "When I design a part, it's often a feedback loop of design, print, modify and print, with ongoing versions. After three or four revisions, the final version doesn't always make it up on Thingiverse" (James, 2019). James supplements this approach to sharing with email- occasionally an individual reaches out requesting the final version of a file or a part that has not yet been posted on Thingiverse (James, 2019).

Elena*, the designer and manufacturer of several open source 3D printers that are also sold commercially, has found it challenging to consistently share the blueprints and accompanying documentation for her printers. One major obstacle that her team has faced over the years is identifying a centralized location online where this data is easily accessible to the majority of the 3D printing community (Elena, 2018). This is because multiple repositories and platforms are leveraged by the community, such as GitHub and Wevolver (Elena, 2018). Over time, Elena has developed a wiki where her company can house this content in a way that best fits their needs (re:3D wiki, 2019). This came after a series of frustrating experiences where platforms that they were using to share open source data changed their set-ups and features. This highlights the ways in which more functional tools, platforms and repositories for diffusing such information could significantly accelerate the process of free innovation. While Elena would be considered someone engaged in producer innovation because she is the founder of a for-profit 3D printing company, the community of consumers which use her 3D printers are free innovators, coming up with new modifications and features that they develop to complement the existing printers. "Innovation support provided by producers can affect the rate and direction of free innovators' efforts, and as a consequence affect the transfer of commercially relevant designs from free innovators to producers" (Hippel, 2016).

Some creators of 3D printing technology have built user innovation into the model. Elena's company produces a large-scale, open source 3D printer which has the capability to print objects

30 times the size of a typical desktop 3D printer. She and her team have used crowdfunding as a way to raise the funds to develop, produce and sell their printers and as a way of engaging would-be users in contributing to the design and development of their printers.
Over the years, they have succeeded in transforming Kickstarter backers and beta testers into long-standing customers and a community of users, a subset of which are free innovators.

In May 2018 Elena launched a new Kickstarter campaign to create a more environmentally sustainable version of the company's 3D printer which would use plastic pellets instead of using the typical extruded filament, enabling the printer to immediately use recycled plastic (Re:3D, 2018). Through user interviews and additional testing, the team identified that in order to develop a pellet printer that individuals would buy, they would need to develop a low-cost dryer, grinder, and feeder system that would accompany the printer and turn trash into pellets. Through the Kickstarter campaign, Elena recruited early adopters for this new printer who are actively engaging with the R&D team at the company. Backers at the top two levels of the Kickstarter campaign could "Be the first in the world to own the beta release of the . . . printer. Receive invites and contribute to regular virtual meet-ups to discuss design requirements and become a pioneer in the future of 3D printing!" (Re:3D, 2018).

By offering exclusive opportunities for these individuals to be part of an elite group of innovators who can contribute to the development of this new 3D printer, Elena as a producer is seeking to transform a subset of the free innovators within their community of 3D printer users into what I call 'hybrid innovators' because in this situation they have transitioned from being free innovators that were not paid, to innovators that are more formally engaged with a producer and compensated because of the recognized value of their contributions by that producer. In backing Elena's Kickstarter campaign, an individual is providing money to Elena to signal his/her desire and enthusiasm for the new 3D printer. If this amount is large enough (within the top two levels), then that individual becomes one of the first people in the world to receive the printer and the opportunity to more actively contribute to the development of the printer.

In his work on free innovation, von Hippel does not discuss in detail how free innovators can transform into innovators that are compensated for their contributions in this way or how innovators can simultaneously be free innovators in one context but compensated innovators in another. Rather, he discusses how a free innovator can turn into a producer, but this assumes that a free innovator becomes the lead in turning a technological artifact into a product that can be purchased on the market as opposed to collaborating with an existing producer. What impact do hybrid innovators have on the overall innovation landscape? The example above provides evidence that an innovator who moves beyond free innovation may accelerate the development of a technology in a manner that he/she would not have before. Different models developed by free innovators turned producers are enabling hybrid innovators to oscillate between free innovation and producer innovation activities.

Once the Kickstarter campaign was fully funded, Elena and her team worked closely with these early adopters, whom they refer to as the "Kickstarter beta testers" to make improvements on the design of the printer. This included the development of a new metal extruder for more durability, an external motor driver and heaters with improved wiring and a screw with a different design for more reliable extrusion. Other communities have taken a similar approach to working closely with a subset of particularly active users who play a role in the design, development and testing of a new product (Stavova, Dedkova, Ukrop, & Matyas, 2018).

5.4 How applications of 3D printing to specific fields create risks and uncertainties and how these are resolved

There are many digital designs for 3D printable objects that must be printed under a certain set of conditions and meet a certain set of strict parameters in order for the final product to be functional, useful and safe. This means that the creators of digital designs for spare parts to an appliance or medical devices take great care in documenting the exact requirements that must be met in order to optimize the quality and integrity of the tool. These conditions cover aspects related to the 3D printer (type of printer, type of material used, temperature of the extruder), techniques used to keep the equipment and the object clean as it is being produced and precautions about how modifications to the digital design or printing parameters could result in a faulty or less functional object. If these conditions are not met, a 3D printed medical device could injure a patient or lead to the malfunction of the device in which the spare part is being used.

As described above, the uncertainty of whether a particular design has been optimized for functionality along with the potential of a design to be incorrectly modified or 3D printed are real reasons why some individuals choose not to make a design widely available. This also points to a lack of infrastructure which would ensure that designs that require a strict set of conditions and parameters to function properly (i.e. type of printing material, specific 3D printer, specific hardware settings on the 3D printer) are downloaded and printed under these requirements. Jane and other creators like her want to ensure that their designs are printed under the right conditions and are modified in ways that do not compromise their functionality. At the same time, they also don't have the bandwidth or technical capabilities or mechanisms to closely monitor how the design files that they open source are utilized.

One approach to address this issue while continuing to facilitate free innovation would be to add features to an existing platform such as Thingiverse that is widely used by the 3D printing community to create a validation process in which certain requirements must be met before an individual can download specific design files. An ongoing project called MakerNet could also help to address this particular challenge. MakerNet is an online platform which enables individuals to create profiles that document their own personal skills and expertise in 3D modeling and 3D printing and the technical capabilities in the spaces where they are doing their work. "As people take classes and use machines, all those learning experiences aggregate to their personal profile, which builds up a meaningful and portable picture of what skills they have. This in turn becomes something that can be connected to job searches and workforce retraining efforts. As we connect spaces into our network, the MakerNet database becomes the global inventory of the skills & training of the world's Makers and of the capacities and equipment of the world's Makerspaces" (MakerNet, 2019). Since a core part of MakerNet's functionality will focus on the validation of specific skills and expertise of individuals, this system could be used to vet individuals to ensure they have the knowledge and resources required to safely utilize a file for a medical device or mission critical part.

Similarly, another interviewee, Nick, works with e-NABLE, an initiative and a volunteer-driven community which focuses on developing low-cost, 3D printed upper limb prosthetics. As a leader of e-NABLE he and his colleagues have had to address the concerns of individuals who have worked in the prosthetics and assistive technologies fields and are accustomed to norms whereby engineers and designers with a professional and academic background in developing prosthetics work with medical professionals to manufacture and fit patients in need of these devices (Nick, 2019). Nick's approach is focused on making the case that a large number of individuals who need prosthetics are not being served by the current system for various reasons, which include the inability to afford a prosthetic and the lack of access to clinics or healthcare facilities where patients can be fitted for a prosthetic. Thus, e-NABLE is filling a critical gap not currently being filled by the existing industry manufacturing prosthetics and the ecosystem of healthcare institutions and organizations supporting these differently-abled individuals (Nick, 2019).

5.5 Users have a general lack of familiarity with how Creative Commons can be used in the sharing, distribution and governance of their digital design files. This includes users who are actively using the licenses.

Creators who generally support open sourcing their design files do not necessarily fully understand the purpose of Creative Commons licenses in relation to 3D digital design files and 3D printing. While I had anticipated that individuals who feel strongly about open source would have a deeper understanding about Creative Commons, this was not in fact the case for the individuals I spoke to during this study. There were varying levels of understanding and awareness about Creative Commons. One interviewee mentioned that she thought Creative Commons could only be used for design files that were artistic, but not for those that were functional, like tools and devices. As result, she did not consider using CC licenses when sharing the digital designs for the devices that she 3D modeled. Another interviewee mentioned he thought he had used CC licensing for a few files he posted to Thingiverse, but could not remember what specific licenses were used. Repeatedly, interviewees noted that even when they used CC licenses they were not convinced about the usefulness of these licenses. From a practical perspective, once a CC license is included in a digital design file, there is no straightforward process or infrastructure for monitoring whether other users are abiding by the guidelines of a specific license. The Attribution-NonCommercial license "lets others remix, tweak, and build upon your work non-commercially, and although their new works must also acknowledge you and be non-commercial, they don't have to license their derivative works on the same terms" (Creative Commons, 2019). But if someone or some company were to take a digital file with this license, make modifications to it and then 3D print and sell these objects as his/her own work, how would the original creator of the file find out?

It might be years before the creator might find out, if ever and even if the creator did discover this violation of the CC license, the legal recourse to prove this could be incredibly cost prohibitive, in particular if the individual creator is up against a larger company, with significantly more resources and a legal team. These challenges are not specific to Creative Commons, but apply to the broader copyright system and have been widely debated and discussed as these issues have compounded in the digital age with online content.

Kurt has been experimenting with different Creative Commons licenses over the years. Kurt initially utilized the non-commercial license, but has backed away from that because there have been instances where he has wanted to download and print someone else’s file for a school fundraiser. As an educator, Kurt creates opportunities when he’s working with students on digital designs to engage them in a conversation around the importance of understanding who created a particular design for an object, where it came from and how it’s been previously used. “I think students have a difficulty seeing that this chunk of plastic that’s being printed out has a legacy and an author and there’s lots of information that actually comes with that design, not just the STL file” (Kurt, 2019).

5.6 Users leverage 3D printing as a technological artifact to tackle a specific long-term problem within a field.

Throughout the interviews conducted, a number of individuals referenced the ways in which they viewed 3D printing as a technology that had the potential to help address a particular pressing problem or issue in the field they were working in that for various reasons had not been resolved. It was not that these users viewed 3D printing as the silver bullet or panacea to such a problem, but rather, that the technology created opportunities to approach an issue in different ways than had been tried thus far.

Interviewee Kurt sought to develop new techniques that would enable students to have a more hands-on educational experience, allowing them to take the concepts they were learning in the classroom and actively apply them through the process of designing, building and making projects and solutions. Kurt thought that 3D printing could be a mechanism through which he could effectively begin to implement these ideas. One example of this is a project that Kurt developed called Zero Things, which focuses on engaging students in using 3D modeling and 3D printing to create objects which celebrate and commemorate important aspects of history or culture (Anderson, 2017). For example, many of Kurt's students are of Latino or Hispanic origin. Realizing that there were very few existing 3D models online to celebrate National Hispanic Heritage Month, Kurt created the National Hispanic Heritage Month Maker Challenge, inviting English Language Learners (ELL), Art, and Spanish educators and students across the country to create digital designs for objects related to Hispanic/Latino culture and heritage. The Challenge resulted in more than 40 different objects, such as a necklace featuring a traditional Mayan design and skull candy mold (Ajima, 2016). This has also created opportunities for students to be more active learners by contributing to an existing body of knowledge that includes their own voices.

Interviewee *Cara is a scholar whose works sits at the intersection of English and disability studies. She has been using 3D modeling and 3D printing to reproduce 19th century literature that was used for education of blind individuals. Many of these material texts are very fragile and not accessible to current visually impaired populations, with many only being available at the physical locations where they are archived. Cara articulates, "Before 3D printing, there was nothing the field was doing to replicate historic tactile print. Part of this is historically there is large visual bias" (Cara, 2018). Up to this point, the use of 3D modeling and printing to create content for the visually impaired had been focused on translation of content designed for visual reading into a format that could be consumed by the blind. However, there have been few developments in terms of effective approaches to making historical texts designed for the visually impaired more widely accessible for today's blind individuals in a manner that would recreate the experience of reading a tactile printed book the way it was designed to be read.

Tactile printed books are books that were printed for the blind with raised Roman letters, dots, and "arbitrary" characters (symbols arbitrarily assigned to represent letters) beginning in the 19^{th} century (Perkins Schools for the Blind, 2019).

In some cases, 3D printing as a technology creates the opportunity for users to fill a need that is not currently being met by the market or industry and may not be met moving forward because companies do not have the financial incentives to develop solutions to address these issues. Interviewee *Kate and her colleagues started a non-profit organization called Tikkun Olam Makers (TOM) aimed at developing customized low-cost assistive technologies for differently-abled individuals (Kate, 2019). Teams of makers or individuals with diverse skills in product design, engineering and digital design and fabrication are paired up with a differently-abled individual or "need knower" who has a particular problem that they are looking to solve (Tikkun Olam Makers, 2019). Working together over the course of several days, the team co-creates a solution and constructs a prototype for a device, testing and reiterating upon the initial design. In many cases the solutions developed by the teams are for specific needs that companies have not yet designed products for or are not interested in developing a solution because there does not seem to be a large enough market (Kate, 2019). Examples of devices developed through the model created by Kate include a device designed to help stroke victims more easily close articles of clothing with zippers on their own and an adjustable guide dog harness which enables an individual to readjust the length and angle of the harness to maximize his/her ability to feel the guide dog's movements (Tikkun Olam Makers, 2019). Former Director of Communications for TOM, Rebecca Fuhrman stated, "When a user has a unique need or the product is too expensive, alternative options to create an affordable custom-made solution remain elusive… We have built a powerful model to address the market failure" (Philips, 2017).

George's experience as a field scientist led him to identify a problem and opportunity- that the tools and technologies frequently used for data collection have historically been expensive and complicated to use. George's efforts to develop low-cost tools for the collection of ocean-related data is also part of the larger citizen science movement, which empowers members of the public who may not have a professional or academic background in science in contributing to a scientific project through activities such as data collection, reporting and analysis. "In citizen science, the public participates voluntarily in the scientific process, addressing real-world problems in ways that may include formulating research questions, conducting scientific experiments, collecting and analyzing data, interpreting results, making new discoveries, developing technologies and applications, and solving complex problems" (CitizenScience.gov, 2019).

5.7 Users can play a critical role in the development and advancement of 3D printing hardware and tools.

When included in the design and development process, users can play a critical role in the evolution of the 3D printers themselves. In some cases, 3D printing manufacturers engage users as a way of testing whether their ideas for a new product would be viable on the market in addition to determining what features should be integrated that were not currently available by existing 3D printers. This was the case when *Greg had his first experience assembling a 3D printer from a kit with his kids in 2010. At the time, MakerBot was the primary desktop consumer 3D printer available. The MakerBot kit was fairly complicated to assemble, even for someone like Greg with a technical and engineering background. After this experience, Greg thought there could be a gap in the consumer desktop 3D printer market. To further explore his hypothesis, Greg assembled a meetup group for 3D printer enthusiasts in the area. These were individuals that wanted to build 3D printers, but also had different backgrounds and varying levels of expertise. Greg described how this group in its early days served as a focus group of sorts for the 3D printer that he would eventually design with the input of these individuals. "So, all these people showed up and I was like, we've got to build printers. Because I was like, who wants a 3D printer? Everybody wants one. But, I was like, okay. What's our budget? Who has $500? A couple people raised their hands. Like retired folks with money. But the kids were like, too expensive. So, I was like, okay, price is going to be the first barrier. So, I thought, we'll do kits." (Greg, 2019). Signature features of the first 3D printer that Greg entered the market with included the compact size of the printer and the simplicity of assembly. Greg's 3D printer was designed to be able to fit into a school backpack, enabling mobile 3D printing, while existing desktop printers were still relatively large, cumbersome and inconvenient to move around (Greg, 2019). In addition, Greg's 3D printer could be assembled without any soldering required, cutting down assembly complexity and time down by hours.

In this context, the individuals who contributed to the design of Greg's 3D printer were free innovators contributing to a project that began as an individual free innovation initiative, morphed into a collaborative free innovation initiative and then enabled Greg to become a producer. Throughout this process Greg was careful to maintain a transparency around the collaborative approach that he took to designing the printer. While he publicly noted that the 3D printer was his original design on the Kickstarter campaign page and the official company website, he also acknowledges that the design is built off of existing open source 3D printers and contributions from the broader 3D printing community. He notes, “The Printrbot is my original design, but borrows from many great designers in the open source 3D printer world (check out reprap.org). This new printer incorporates some of the best practices out there” (Printrbot, 2011).

5.8 Organizations that previously focused on developing 3D assets specifically for 3D printing are learning that this was a myopic approach.

As the amount and variety of 3D content created across fields continues to grow, there is ongoing discussion about the need to improve the standardization, interoperability and management of 3D assets to ensure long-term usability, maximize security and versatility of use across technologies. 3D digital design files may be created with the original intention of being 3D printed, but once these assets are publicly shared with a broader set of users, they may use them in ways that were unanticipated by the original creators.

Violet* works for an agency which develops biomedical 3D assets for use by researchers and medical professionals. These assets are made available through an online repository. The initiative was designed five years ago with the assumption that the value of these 3D digital files to the biomedical community would be in the form of 3D printable models. However, as other technologies have become relevant to the biomedical field such as virtual reality (VR), Violet’s perspective has shifted (Violet, 2018). Since the launch of the repository, users have leveraged the 3D assets in other ways, such as importing the models into augmented reality and virtual reality environments to design surgical simulations or interactive educational experiences for graduate or medical students (Violet, 2018). As a result, Violet's team has been re-examining the processes, systems and technical choices they have made in an effort to develop an approach to managing their 3D assets that would provide users with greater flexibility to use these assets across different technologies (Violet, 2018). U.S. federal government agencies and offices such as the National Institute of Standards and Technology, the Library of Congress and Department of Defense have been convening government colleagues and non-governmental stakeholders across academia and industry whose work involves the creation of 3D models in an effort to facilitate discussions around topics ranging from the standardization of data packages and best practices for 3D asset management to leveraging blockchain to improve the security of digital design files and maintain a record which ensures the structural integrity of files as they are downloaded and in some cases modified (Library of Congress, 2018).

Predicting future uses of a technology can be facilitated by observing activities emerging from within the community of 3D printing users. Users of 3D printing technologies can play a significant role around the innovation of the features and functionality. This includes contributions provided by users for 3D modeling software and 3D printing hardware. Contributions to these technologies can take different forms including informal feedback (i.e., through online forums, wikis and blogs) and formal feedback (i.e., through manufacturer administered customer surveys, focus groups or interviews).

Violet's team is in the process of repositioning the platform they developed to acknowledge that the collection of digital assets that they have developed over the last several years is actually being leveraged for more than 3D printing. The team has remained actively involved in ongoing initiatives that aim to make 3D digital design files technology agnostic. Violet describes, "Don't box in what the repository is because you don't know what your user is going to want. You'll have info and metadata that is specific to 3D printing but at the end of the day you have digital assets that can be used across a broad variety of applications" (Violet, 2018). For those organizations who are concerned with the ways that 3D digital assets are used across technologies, these entities are also asking important IP questions. Do creators of 3D digital design files understand that their designs could be leveraged across different technologies? Should there be a mechanism which enables creators to articulate which technologies the design file can be used with upon sharing online? If a 3D digital design file was created with the intention of being 3D printed by the original creator but is then modified by another user to be leveraged in a VR environment, how do we ensure attribution across mediums? These are the types of questions that arise as more 3D digital assets are available for use across various technologies.

5.9 An institution's or field's overall policies or norms around IP can depart from or inform the approach a user takes when it comes to 3D printing.

Colleges and universities are typically institutions which have strict and well-defined policies around IP, coordinated with the help of tech transfer offices. However, when interviewing 3D printing users and 3D printing educators working in makerspaces within different higher education institutions, it became clear that these environments are not necessarily subject to the same IP rules as research labs on the same campus.

*Nan is an architect by training and the director of a makerspace at a college in New York. Students across different departments are welcome to use the makerspace for both course-related and personal projects. Nan articulates that because the makerspace is not funded by research dollars, the space has a clear policy that all IP created within the space is retained by the individual students (Nan, 2018). Similarly, *Ted is a professor at a business school in the Midwest which has its own makerspace. Ted describes how the university has not expressed concerns about the IP generated in the makerspace, making it possible for the IP developed to remain with students (Ted, 2018). This means that any IP created through the 3D modeling and 3D printing conducted by users of the space will also remain with their original creators. On the other hand, the general norms of a field can drive the approach to sharing 3D assets.

*Gus is an assistive technology specialist where he works within a county that contains 140 school districts. In his role, Gus works with visually impaired students and their teachers to design tools, technologies and aids aimed at helping these students to learn specific concepts across subject areas (Gus, 2018). As technology increasingly becomes an important part of education, there is an increasing demand for assistive technologies for students who are visually impaired. Over the past 5 years, 3D printing has become a technology that assistive technology specialists are adopting to help expand their capabilities for developing these solutions for students. In developing tools that are fully 3D printed or have a 3D printed element to them, Gus tries to share as much as possible- almost everything- on Thingiverse (Gus, 2018). None of his creations are patented and he typically provides detailed instructions and documentation for how to create and use them. A large motivating factor for widely disseminating this content is because the field of designing assistive technologies for visually impaired students is so small and there is a general culture of community members helping each other to continue to broaden accessibility for their students. “In this field, you share out as much as you can. Because you’ll get that back in a situation when you might not know what to do. It makes our lives and our students lives way easier as we face these challenges every day” (Gus, 2018).

In some cases, a field’s approach to IP may be challenged by a user or organization leveraging 3D printing to broaden access to a particular technological artifact or solution. This is the case with e-NABLE, which is able to design and distribute low-cost prosthetics to underserved populations because it makes the designs for these prosthetics freely available through a variety of Creative Commons licenses. “e-NABLE is a global network of volunteers who are using their 3D printers, design skills, and personal time to create free 3D printed prosthetic hands for those in need – with the goal of providing them to underserved populations around the world.
We are not a company and we do not sell these devices. We describe e-NABLE as a “movement” because there is no single legal entity or organization that represents it” (e-NABLE, 2019a).

As an academic, Cara indicated that her perspective is that widely sharing her research and ideas is central to her work as an English scholar. While this may not be the perspective of all her peers, she talked about the ways in which the digital design files that she and her colleagues are creating are an extension of her research. One project she is working on involves creating 3D printed replicas from historical books for blind and low-vision readers printed between 1830 and 1910. The digital design files for these replicas are being made freely available online so that users around the world have the opportunity to download and print their own versions (Touch

This Page, 2019). For Cara and her colleagues who are also scholars in the areas of English and Library Science, the goal of this project is to make artifacts that were previously unaccessible, more widely accessible. “Even from a less altruistic side, in terms of our careers, the value in this is not in monetizing it, the value is in doing it. We’re not incentivized to make money out of it, but the real value for me as a scholar is to be able to write about it. This is the amazing thing about academia- you get paid to have ideas and share them with the public” (Cara, 2018).

Historically, a particular field’s approach to IP can evolve over time as a result of different factors, including emerging business models, changing goals and the introduction of new technologies. In discussing the IP issues around 3D printing, interviewee *Carl, an English scholar cited the changing approach to IP in the newspaper industry and how these changes offer insights into how perspectives around IP may change with 3D printing over time. 19th century newspaper texts are one of Carl’s specific areas of research. By the 19th century, the printing press had been invented and led to the explosion of newspapers, which went from hundreds to tens of thousands in the U.S. Editors of these papers would mail their newspapers to each other to look through the content, identify articles and stories that they thought their readership would find interesting and simply reprint these in their own papers (Carl, 2019). At this time, laws were structured in a way that made it easier for newspapers to maximize the distribution of knowledge, but resulted in questions around whether the authors of these texts were being properly compensated and/or recognized. “The periodical press in the United States depended on “exchanges,” through which editors subscribed to each other’s publications (paying little to no postage for the privilege), and borrowed content promiscuously from each other’s subscriptions. Texts of all kinds were reprinted—typically without authors’ or publishers’ permission—across books, newspapers, and magazines. Content shared through the exchange system was not protected under intellectual property law. Instead, periodical texts were considered common property for reprinting, with or without modification—much as articles, music videos, and other content are shared online today among blogs and social media sites" (Cordell, 2015). Similar to the reactions and sentiments expressed by 3D printing users today, some writers in the 19th century thought these practices were akin to theft while others sought to utilize the reprinting practices as opportunities to develop their reputation on a broader scale and transform these into paid writing jobs (Cordell, 2015).

6 CHAPTER 6 Case Studies

After conducting the 20 interviews with individuals using 3D printing across different fields and industries, three phenomena observed were then further developed into detailed full case studies through a combination of additional primary and secondary research. The content of these interviews was chosen after all interviews had been transcribed, coded for key themes and analyzed. Each case study was specifically developed because each case provided the opportunity to further examine: 1) how 3D printing users make decisions about whether to use CC licenses; 2) alternative approaches users take when they do not use CC licenses to share their work; and 3) an investigation of the significant factors and conditions that affect whether a user decides to share or not share digital design files. The three case studies also further illuminate unexpected findings resulting from the analysis of the initial interviews about how field-specific challenges, policies and norms can play critical roles in determining a) how 3D digital design files are distributed; b) the role that IP plays in accelerating advancement of 3D printing through the tools and software that make 3D printing possible and; c) the importance of organizing the community of 3D printing users in a manner that is conducive to collaboration, sharing and utilization of the assets that they have developed.

6.1 Case Study 1: Humanitarian Macgyvering: Balancing the benefits and risks of sharing solutions

This case study examines the use of 3D printing within the context of humanitarian and international development initiatives specific to the digital designs of devices and solutions. IP issues that are relevant to the application of the technology within this sector include uncertainties around the applicability of Creative Commons to digital designs, the need to control

IP in order to ensure safety and the risk of violating others' IP in the face of designing a solution in life or death situations.

When talking to people about what she does, Jane*[1] will often describe her work as "Macgyvering" in humanitarian situations. With a background as an industrial designer, Jane first came across a 3D printer in college, but as an artist and maker who had mostly focused on creating things with her hands through carving and sketching, she shunned the idea of using this technology. In her words, "technology was bullshit and it felt like cheating" (Jane, 2018).

It wasn't until several years later when she joined a non-profit organization that was focused on using "cutting edge technology" such as drones and 3D printing to solve pressing global challenges that Jane began to realize the potential that 3D printing could have in helping to solve real-world problems. While the non-profit organization fell short of its goals and she left, Jane's experience inspired her to figure out how 3D printing could be used to solve problems in communities faced with crisis level challenges. When a massive earthquake hit Haiti in January 2010, Jane travelled to the island in the aftermath to join several colleagues who were already working closely with local community organizations on relief, recovery and rebuilding efforts.

6.1.1 Innovating with 3D printing in high crisis, low-resource environments

The 7.0 earthquake left 220,000 people dead and 300,000 injured (Knox, 2015). While Jane was in Haiti, she noticed specific patterns in the problems leading to the breakdown of critical infrastructure and equipment that if addressed, had the potential to save lives. This included

[1] Name has been changed for the purposes of anonymization

visiting a water treatment facility that was falling apart, leaving hundreds of people without access to clean water because of missing washers and screws and seeing broken life-saving medical equipment such as gas cylinder regulators and baby incubators that could not be used because of the lack of spare parts (Jane, 2018).

One night, a friend who was a nurse assisting pregnant women in labor, had no access to umbilical cord clamps. She had to use the fingers from her last pair of latex gloves to tie off the umbilical cord during a delivery. That night she had to deliver several more babies of mothers who were potentially HIV positive without gloves, putting her at risk for contracting the virus. This was a turning point for Jane who again saw that this as an unnecessary risk her friend had to take.

In a mosquito infested, sweltering shipping container in Haiti, Jane took a MakerBot 3D printer that she had received as a donation after posting a message on Facebook and taught herself how to use it. She had learned how to use Solidworks, a CAD-based 3D modeling software in college, but admittedly had really only used it to complete school assignments. After hours of troubleshooting on the phone with a team at MakerBot's then headquarters in Brooklyn, Jane had designed a low-cost, 3D printed umbilical cord clamp that could be produced locally, in real-time and provided a safer, more hygienic and cheaper solution. "The main supply chain for these items comprises volunteers from the United States, who bring them in their backpacks. Most clinics could not secure a supply. When they are available on the market, they typically cost $1, and can cost as much as $3. A 3D printed clamp costs just $0.60" (James & James, 2016).

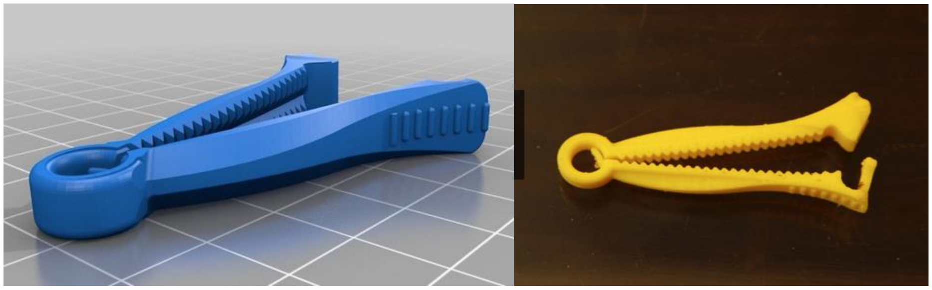

Figure 2: 3D model and 3D printed umbilical cord clamp. Photo credit: Field Ready

With hospitals destroyed by the earthquake and a huge need for medical devices and tools to support the triage effort, Jane realized that 3D printing could be a way to “create a factory of basic and critical medical items” (Jane, 2018). When she and her team deploy to a particular area, she will bring a standard set of tools, technology and equipment. If she can get access to a consistent source of electricity, she can use the digital design files she has pre-loaded onto her computer to produce any one of these 15 devices. In order to ensure that a larger group of individuals from the community had access to these resources, Jane has focused on collaborating with local organizations and relief groups to teach others how to 3D model solutions, use and maintain 3D printers in order to scale relief efforts (Field Ready, 2019d). Figure 3 illustrates members using 3D printing in rebuilding activities in their community. To make the 3D models and files broadly available, her organization has made them available through the 3D printing sharing platform Thingiverse (Thingiverse.com, 2019d). Field Ready, the formal non-profit organization created by Jane and her colleagues describes the scope of its work in three areas: making (specializing in local manufacturing, fabricating and repairing useful things in difficult environments), training (strengthening the skills, competencies and abilities of aid workers and disaster-affected people) and innovating (pioneering ways to transform humanitarian logistics) (Field Ready, 2019c).

Figure 3: Local community relief disaster effort using 3D printing. Photo credit: Field Ready

6.1.2 Developing a library of low-cost tools with limitations to distribution

Over the last 6 years, Field Ready has developed a library of more than 270 tools and devices designed for use in high crisis situations, humanitarian relief efforts within low resource environments. About one-third of these solutions use 3D printing. Since the team's first trip to Haiti in 2013, they have worked in Nepal in the aftermath of the 2015 earthquake, in Syria beginning in 2016 in the midst of the country's ongoing civil war and in the U.S. Virgin Islands in 2017 after Hurricanes Maria and Irma devastated these communities (Field Ready, 2019a, 2019b; Peters, 2017). The innovations that they have developed in working with these communities includes a fetoscope to monitor the development and health of a baby in the womb and a low-cost airbag used to rescue people who have been buried by rubble (S. Santoso, Gage, & Bloch, 2017; Terdiman, 2018). Of the 270 solutions that the team has created, only 20 of them have been made publicly available because of the risks and concerns with releasing files for devices that require a very specific set of expertise, conditions and parameters in order to ensure that an object will function the way it should. Some of these unreleased solutions are designed to be completely 3D printed, others may have some 3D printed parts or components and many solutions are designed to be created with completely different tools and materials altogether (Jane, 2018).

When Jane and her team are creating a solution in real time, the approach is to develop something that solves the problem, is functional and relatively reliable. The realities are, however, that the team does not have the time and resources in the field to thoroughly test solutions before deploying them. In other words, the solutions they develop are relatively optimized for the initial conditions that they were designed for, but each device or solution needs to undergo further scientific and technical testing in order to establish a set of specifications and ensure that a particular solution meets the requirements and performance parameters. These parameters must be established and met in order for Jane and her colleagues to be able to broadly release the design files and documentation for the solutions, regardless of whether they are 3D printed or not. While conducting this dissertation research, the team was exploring opportunities to conduct this much needed research and testing. Such efforts could be a collaboration with the U.S. Department of Energy National Laboratory, the Air Force Research Laboratory, the National Institutes of Health or an institution like America Makes, which focuses specifically on research and multi-sector collaborations to spur further development of additive manufacturing (Jane, 2018).

6.1.3 Leveraging Creative Commons to facilitate use and sharing

The 20 solutions that Jane's team has made publicly available include designs for tools, medical devices and spare parts, all for 3D printing (Appendix 9.4). These include a body fat caliper, a set square, a vacuum suction pump connector, a wrist brace, a device that can turn a bottle into a safe needle disposal unit and a mechanism to fix a broken chair lever (Thingiverse.com, 2019d). All designs use the Creative Commons Attributions license, which is the most relaxed of the CC licenses. The CC Attribution license "lets others distribute, remix, tweak, and build upon your work, even commercially, as long as they credit you for the original creation" (Creative Commons, 2018). The use of this license, which is the least restrictive and encourages the widest dissemination and distribution of content, is consistent with Jane's perspective on the value of open source and broadly sharing the solutions created by her organization. In her words, she prefers open source because "people can hack it and make it better." However, the challenge with their solutions is that they need a process of accountability and monitoring to make sure that subsequent uses and modifications of these solutions maintain the integrity and functionality of a device or truly improve upon it (Jane, 2018).

6.1.4 Creating conditions for collaborative free innovation

In this sense, the innovations that Jane and her team work on are "collaborative innovation" projects as opposed to "individual innovation" projects (Hippel, 2016). For Jane's work in the humanitarian and international development space, collaborative innovation is key because local members of a particular community and culture have insights and knowledge needed to develop effective solutions for a particular problem and context. Rather than *designing for* users, Jane *designs with* users (Dietmar Harhoff & Karim R. Lakhani, 2016; Flowers et al., 2008; Hippel, 2005; Hyysalo, Jensen, & Oudshoorn, 2016). This results in innovations that are customized to the needs of a particular community and account for critical attributes like cultural identity and social norms that can determine whether an innovation is used and widely adopted. For example, the digital design for the 3D printed fetoscope was leveraged by a team of designers and medical professionals in Kenya who realized that this medical tool could be more efficiently made out of local wood using a lathe; both material and equipment are widely available in the country. Jane and her team coordinated with the Kenyan team, answering questions about the digital design and helping compare the functionality of the wooden versions against the 3D printed ones. When free innovations are designed collaboratively, "(e)ach individual participant incurs the design cost of doing a fraction of the project work but, if intending to use it, obtains the value of the entire design, including additions and improvements generated by others"(Hippel, 2016).

6.1.5 Addressing safety of 3D printed devices that require structural integrity

Jane's concerns about how to ensure that her organization's innovations are used properly and safely are not just hypothetical. In a previous incident, an individual outside of her organization leveraged the design for the umbilical cord clamp, which was printed, but then broke. It turned out that the user did not follow the specifications that accompanied the design file, which explicitly notes that the device should be printed using Acrylonitrile butadiene styrene (ABS), a type of thermoplastic polymer filament commonly used with desktop 3D printers (Jane, 2018). Instead, the user printed the clamp with polylactic acid (PLA), a different kind of thermoplastic that is also commonly used with 3D printers and is generally considered more eco-friendly because it is derived from renewable resources such as corn starch and cassava. PLA has different structural qualities than ABS and is generally more brittle. Because umbilical cord clamps require a certain tensile characteristic or a specific amount of give and flexibility, ABS is the more ideal material choice (Jane, personal communication, Sept. 30, 2018).

The solutions that have been publicly released have been internally tested within Jane's organization and in some cases in collaboration with MIT's Lincoln Lab. Partnering with outside academic institutions which have the technology and equipment in addition to the scientific and technical expertise necessary to test and evaluate the integrity of the designs under different conditions is critical. Following successful testing and evaluation, the organization is able to release the solutions to the public while minimizing the risk of unintended negative consequences. Jane explained, "If we create medical equipment and someone fucks up the code and then it comes back to us, but it wasn't us, how do we track this? If someone alters this, how do you create a chain or tree so you can see how something has been modified?" (Jane, personal communication, Sept. 30, 2018). This is about creating a system of accountability which could exist independent of the traditional IP system of patents, copyrights and trademarks. Such a system would provide Jane and her team, along with other contributors of these projects with the kind of traceability and transparency that would ensure that mistakes or misuse can be identified, traced back to their true origins and resolved. However, there are limits to what extent such a system can avoid harmful modifications or use.

6.1.6 Understanding how and why potential IP violations could be overlooked

In addition to the concerns associated with ensuring that the use of their designs can be closely monitored for health and safety purposes, Jane acknowledges that there are also IP questions that stem from the very real possibility that any number of the devices her team has developed may be violating existing patents. But as Jane describes, her work can be “a matter of life or death” and if it is a question of saving someone’s life or violating a patent, “the former wins out, hands down,” she explained. Jane articulates that her organization has not closely examined the extent to which the innovations they’ve developed could be violating existing patents- they do not have the bandwidth or resources to undertake this process and Jane admits that it is not as much of a priority compared to saving lives, rebuilding the communities that they are working in and ensuring that others have access to the innovations they have developed. She also asserts that if a large company claimed that Jane’s team was in violation of one of their patents, such a company would think twice about pursuing severe legal action against them because of the negative optics that it could bring the company (Jane, 2018). At the core of this idea is the notion that the work that Jane’s team is doing often boils down to saving lives in situations of natural disaster or conflicts, and that as an organization, they may end up breaking certain regulations and laws in order to do this. Jane realizes that this is in no way a real solution to some of the outstanding patent questions that she has, but is a way for her and her colleagues to deal with these uncertainties in the absence of having the resources and expertise to resolve these matters.

6.1.7 Negotiating with IP and uncertainties about how Creative Commons applies

Jane’s team experiences an ongoing negotiation around how to “protect” their own IP and their roles as free innovators. The team’s goal is to maximize the number of individuals who have access to their solutions. For the solutions that they have already publicly shared, they have released the digital files under Creative Commons licenses. However, Jane explained that they are unsure as to how much Creative Commons licenses are relevant, given that their solutions are utilitarian and functional, meaning that they may be governed by patent law. They have also discussed models that could both provide their organization with financial sustainability and facilitate their goal, such as licensing solutions to companies while providing these solutions to humanitarian groups for free. This is not something that Jane's organization currently does, but if they were to do this, they would move from the space of free innovation to what I call hybrid innovation. This transformation may be necessary in order to ensure that Jane's team can continue to foster free innovation activities while addressing the need to develop sources of revenue to sustain the organization. In freely sharing the solutions that they've developed, Jane believes this is also a way of discouraging companies and other organizations that might seek to capitalize on commercializing similar solutions and excluding those who need them the most.

Because Jane's team actively recognizes the value of open source and the ability for others to build off of the work of others, a number of the solutions that they have developed have been based on pre-existing open source projects. One example of this is the otoscope, which is a medical device used to look into the ears and screen for infections (Thapa, 2017). The digital design of the otoscope developed by Jane's team is based on an existing model that was then modified and shared (Jane, 2018). Because the team creates work based on those of other creators, it is also important for them to have an infrastructure and set of processes that allows them to document the existing projects and resources that they use to design their solutions in addition to being able to monitor how others are using what they've created. Such documentation could also be helpful in the event that Jane is approached by an organization which claims that they are in violation of one of their patents or other IP. If Jane's team created a solution based on an open source device and it turned out that this open source device was in violation of a patent owned by a company (but Jane's team leveraged this knowledge under the assumption that the solution was open source), could Jane's team be held liable for infringement? It is difficult to know whether documentation which illustrates that the device was positioned as open source could be favorable for Jane's team.

Since she first started experimenting with 3D printing to develop low-cost solutions for low-resource settings, Jane's perspective on the sustainability and practicality of using the technology has significantly evolved. At the most basic level, using a 3D printer requires a consistent, uninterrupted power source, which is often not available in the regions where she and her team have been working. Jane has also realized that it can be very difficult for a community to maintain a 3D printer and have consistent and ready access to the plastic filament and parts needed, especially once her team has left that community. In many cases, Jane and her team were the first to bring the technology to a particular community, which means that there are not already local resources and infrastructure on the ground to foster ongoing use of the technology. This is the case even given the model that Jane has established in which she collaborates with local community leaders to engage them in co-designing solutions and learning how to use the technology.

Over time, Jane's perspective on solution development has become informed by one core idea- to develop devices that can be produced locally, by the community, using tools, technologies and materials that are readily available in that community. As a result, Jane's understanding of the ways that 3D printing can be useful in such environments has evolved. The technology may in certain contexts be useful in producing final solutions, but in other cases, 3D printing might be more useful in earlier stages of the development of a solution, with the final device being manufactured using more locally available materials and technologies. Jane articulates, “The goal is not the tech. It’s using local resources, local people, materials and resources so that we can replicate what our team does even after we’re gone. So we only bring in 3D printing where it makes sense.” This mentality is also one that is driven by an understanding that Jane and her team are playing a critical role in the rebuilding of a community in the face of a devastating event and that there are economic, social and political implications that are connected to the decisions that they make throughout the work that they do. Jane summarizes that “3D printing is amazing when it works. But if you find a way to do something locally, then it’s better to do it locally. If someone can make a widget in the country and they need a job, why would you bring in a machine for them to do it?”

6.1.8 Developing a technological infrastructure to further facilitate sharing while minimizing risks

The issues and complexities that Jane and her team have dealt with through their humanitarian work illustrate how 3D printing is being leveraged to solve critical needs and important challenges, but that its impact is limited by outstanding questions about how to govern the use of the digital designs for solutions. Addressing these questions is critical to ensuring that the production and distribution of these devices are done safely and within society’s generally accepted norms around IP, so that Jane’s organization can maximize the impact of their work by distributing their solutions as widely as possible, without becoming involved in legal battles from companies or other organizations which might claim that the organization is in violation of their IP rights. All of Jane’s work is informed by a systems thinking perspective, which is driven by identifying a problem within a system and then conducting a needs assessment. These systems existed and functioned long before Jane and her team arrived, so for her, it is critical that she develop an intervention or solution that can help keep the system functioning and if possible, improve the system beyond its previous state.

To bring this to life, Jane provides a hypothetical example. If the people of a particular country needed coats, the short-term fix would be to collect coats from other parts of the world that have them and send the coats over. But for the cost of collecting and flying the coats there, one might have been able to purchase llamas or sheep whose wool could be used to make those coats, but also used for a variety of other purposes, potentially addressing additional needs and help the people of that country develop financially sustainable businesses moving forward. The key here is to balance short term immediate needs with thinking long term about what will ultimately improve the system as a whole.

In examining Jane's approach to solving these challenges, research on cyberinfrastructure can provide insights into the kinds of mechanisms that can help foster the design, development and sharing of these solutions, which are technologically enabled and globally distributed. Thus far, Jane's team has leveraged a combination of tools, applications and platforms in an effort to provide the data and documentation necessary for an individual user to be able to replicate the functionality and quality of a particular solution remotely and asynchronously. A humanitarian worker in Indonesia should be able to produce a 3D printed umbilical cord clamp that mirrors the one produced by a nurse in Ghana if both individuals have the skills, specifications, technology and materials necessary. In order to more effectively facilitate the use of these solutions and to further foster the generation of additional solutions that are built upon those created by Jane's team, there must be a mechanism which helps to determine whether an individual meets the appropriate conditions and requirements. A system could be developed that would help small organizations like Jane's, which want to ensure that their solutions are widely shared, but to the individuals and organizations who have the skills, experience and resources to make sure that the solutions that get produced are safe, robust and functional. Such a platform could safely centralize the design files, documentation and other data for solutions, automatically broker transactions once an individual or organization has demonstrated they meet the requirements and can provide a way for members of this community to see how solutions have been forked and modified. Members of Jane's team are currently working on a platform called MakerNet that would feature some of these functionalities to provide a process and infrastructure to enable the organization and similar entities to vet individuals and streamline this process, which could be described as next generation supply chain management and in real-time manufacturing.

While von Hippel discusses the ways in which free innovation is driven by individuals' personal use of the innovation, opportunity to help others, personal enjoyment and personal learning, I would argue that in certain contexts such as the one described in this analytical case study, personal survival and the collective survival of a community create an urgency and attract a larger group of innovators that can accelerate, but also complicate the innovation process in significant ways.

6.2 Case Study 2: The Laser Cowboys: Developing 3D tools to preserve and broaden access to historical and cultural artifacts

This case study examines the role of 3D tools and software which make it easier for individuals to create 3D models, either by digitizing existing physical objects into 3D models, modifying existing digital design files or creating new ones from scratch. This case also explores the complex issues and questions which arise in the sharing of digital designs of existing objects which were originally created under circumstances where digital sharing was not an option. In this case I observe how an institution took learnings from developing a "locked" 3D model viewer to develop a set of open source 3D tools for broader use by the public. We also look at an example of the way a sacred, historical artifact was widely shared with the public by negotiating the digitization and sharing of the object in a manner that respected the wishes and values of a particular community.

One must acknowledge that 3D printing as a technology cannot be discussed without examining the development and use of the collection of software, scanners and other tools that are making it easier for individuals to create 3D models and expanding the capabilities of 3D modeling, whether through digital design, scanning or some combination of both. 3D models are required in order to 3D print an object.

Kevin[*2] works for the Smithsonian, a U.S. federal agency, which was founded as "an establishment for the increase and diffusion of knowledge among men" (Smithsonian, 2018). This institution collaborates with various national and international museums including those

[2] Name has been changed for the purposes of anonymization

that specialize in art, history and culture. In his role, Kevin and his colleagues have helped to pioneer the institution's 3D digitization efforts- the process of taking physical artifacts, scanning them and digitizing them into 3D models ("Smithsonian 3D Digitization| 3d.si.edu," 2019). The models range from the Apollo 11 command module hatch and woolly mammoth to the life masks of Abraham Lincoln. These models of artifacts from different museum collections have become part of a growing digital collection that is valuable for preservation and educational purposes. Today, the institution hosts Smithsonian 3D, a publicly accessible online repository where individuals can view more than 100 individual artifacts in 3D, learn more about these artifacts and in some cases download the actual digital files ("Smithsonian 3D Digitization| 3d.si.edu," 2019). Because the institution has more than 155 million artifacts, Kevin's team is focused on developing the tools, processes and techniques that will enable them to digitize and share more of this massive collection with greater efficiency.

6.2.1 Understanding 3D Digitization: From exhibits to archiving

The institution's first use of 3D scanning was originally for the purpose of creating exhibits. In 2006, Kevin was working as an exhibit sculptor when he and a colleague were asked to create life size models of ocean creatures. An exhibit sculptor is someone who designs and builds models for exhibits in museums and similar settings. In an effort to streamline this process, Kevin was able to work with a third party which digitally scanned a scale model of the animals and created 3D digital files (Kevin, 2018). Using these files, Kevin created what would eventually become the final models of the ocean creatures using a CNC milling machine in combination with traditional clay sculpting. Quickly realizing the various possibilities of using 3D scanning and digitization technology for the Smithsonian, Kevin put in an internal request to purchase a Z Corp 650 3D printer and a Minolta laser scanner. Together, these two tools transformed how exhibits were made at Kevin's institution, from being created primarily by hand to being digitally designed and constructed (Kevin, 2018).

6.2.2 Developing the digital tools necessary to create a collection of 3D artifacts

Eventually, the Chief Information Officer took notice and Kevin and his colleague had the opportunity expand their use of 3D digitization beyond exhibits. Today, the division that Kevin works in is part of the Office of the CIO and is focused on expanding the quality, quantity and impact of its digitized collections across the museums that it works with. Because Kevin's team is focused on digitizing artifacts which have cultural, historical, social and economic value, a priority for his team has been to develop a process for scanning and digitizing artifacts that renders the highest resolution and most interoperable files possible. Due to these unique needs, Kevin's team has continued to develop their own software and tools designed to optimize this process (Kevin, 2018). Having gained the support of senior leadership within the institution, Kevin's team has had the resources and key opportunities to develop collaborations with other organizations that have allowed them to design innovative applications that could push the boundaries of what individuals could do with 3D models. The need for more robust tools to make the digitization process more efficient and to support a broader set of applications for these models afterwards has led Kevin to collaborate with industry and academic institutions who are leading experts in 3D modeling, 3D scanning and 3D printing, including Autodesk, Google and USC Institute for Creative Technologies (Smithsonian Digitization Program Office, 2018a).

6.2.3 Realizing the value of these tools to individuals outside of the Smithsonian

In 2013, Kevin's team launched a 3D model viewer, which enabled users to view a model of an artifact from different directions and perspectives and learn more about the artifact and its significance ("Smithsonian 3D Digitization| 3d.si.edu," 2019). At the time, this viewer was extremely unique in the way it allowed individuals to examine and explore the 3D models online, with unprecedented depth and spatial qualities. This initial version of the viewer was developed in conjunction with a company specializing in digital design and 3D modeling software and was "locked down," meaning that it was not open source. Kevin recalls hearing feedback from the broader community of organizations and individuals using the tool about how helpful it would have been for the viewer to have been open source (Kevin, 2018). Over the years, Kevin and his team have sought to develop an internal culture within their organization that values making the tools that they create for various aspects of digitization as accessible to the public as possible. This approach aligns with the original mission upon which the institution was founded and its purpose, which is simple and ambitious- the increase and diffusion of knowledge.

As Kevin's team expands the volume of artifacts it is digitizing and the level of complexity has grown, this has led to several projects which aim to create a long-term model for the institution to build upon its current collection of 3D digitized artifacts. In 2018, they developed a strategy which includes the creation of a 3D metadata model and several automated tools that will optimize data processing, standardize how content is created so that 3D models can be leveraged across different kinds of technologies (e.g., AR, VR, 3D printing) and enable institutions and other users to engage in more robust storytelling with 3D content (Smithsonian Digitization Program Office, 2018b). All of these tools will be open source (Kevin, 2018). The metadata model will provide detailed information about the raw data that the 3D models were created from and will document the processes that were undertaken to transform the data into models and become part of the repository. Creating a 3D metadata model is critical because as technologies evolve, Kevin is focused on ensuring that in the future, individuals will have the information necessary to continue utilizing the data. This is about maximizing the usability and interoperability of the data and ensuring that critical institutional information and tacit knowledge is shared (Smithsonian Digitization Program Office, 2018b).

The development of these automated open source tools has also been informed by Kevin's ability to find individuals with the right skills that recognize the value of openly sharing what they have developed. A combination of individuals from Kevin's team and several contracted programmers are working on these efforts. The open source feature of these tools has been written into corresponding contracts associated with these projects.

6.2.4 Identifying IP and non-IP governance issues in sharing 3D models

The approach to sharing shifts when we go from 3D modeling tools and digitization software to discussing the digital models that Kevin's team creates from various artifacts. We must differentiate the sharing of tools and software versus the objects created through them. This has to do with the nature of the various objects that they are working with and the culture of the GLAM (i.e., gallery, libraries, archives, museums) sector. There are specific contexts in which digitized artifacts by one institution may be determined as inappropriate for sharing with the public. The Smithsonian has a specific directive which governs its digital assets- how they can be shared, accessed and used by individuals within the institution and by those outside of the institution. Under section VII. Allowable Restriction Categories, the directive articulates:

> "For a variety of legal, ethical and policy reasons, it may be necessary at times to restrict access to and use of the digital assets internally, externally or both. The most common types of restrictions are set forth below. Each director, or his or her designee, shall be responsible for determining when restrictions other than legal are mandatory, and when they may be waived by the holding unit. When use of a digital asset is restricted, the nature of the restriction must be documented, preferably in the metadata that describes the asset or at a minimum in writing when responding to a request for use" (Smithsonian Institution, 2011).

Among the categories that are subject to these restrictions are those objects for which related IP rights are not fully owned by the institution, objects that possess personally identifiable information, objects of repatriation (i.e., cultural objects or human remains that have been determined as having been acquired in an inappropriate manner from a tribal community or otherwise) and objects of cultural sensitivity. An object which falls into one or more of these categories could for example, be shared on the institution's site for public viewing, but the actual digital file may not be available for download. In other cases, an object might be digitized and added to the digital collection, but not publicly available for viewing online. In this context, the governance of these digital models is dictated by more than just IP issues. There are questions about the potentially negative implications on culture, privacy and ethics if these models are distributed and then reappropriated in offensive or inappropriate ways.

When a user visits the Smithsonian 3D platform, he/she will see a gallery of 3D models that they can view in greater detail by clicking on a particular model. When a model is selected a separate subpage pops up where the user can explore the model using the 3D viewer, zooming in and examining the model from many different angles. For certain models, a user can click on the information icon located to the upper right of the model and the option to download the model appears. Models available for download can have one or two options: 1) a 3D render ready model that can be used for various purposes such as animation, VR and digital game design; 2) a 3D print ready model. When a 3D print ready model is available, it is provided in the form of an .STL file. Before a user can download this file, he/she must consent to the Smithsonian disclaimer and terms of use articulated by the institution. The disclaimer describes that the user assumes any risk or liability related to the design, scanning, alteration, upload, download, manufacture or use by themselves or others of the files and that the user does not hold the Smithsonian responsible for claims arising from the download or use of the files or their printed forms which lead to claims of damage, injury, death or other harm (Smithsonian 3D, 2019b). The terms of use broadly apply to all content on the Smithsonian 3D website, which includes the 3D models, but also includes videos, blog posts and other content made available. The Smithsonian's terms of use is guided by its mission "for the increase and diffusion of knowledge" (Smithsonian 3D, 2019a). The institution describes that all content made available on the site can be utilized for fair use (personal, educational and non-commercial use) as defined by copyright law and use of this content should adhere to the following additional requirements (Smithsonian 3D, 2019a):

- You must cite the author and source of the Content as you would material from any printed work.

- You must also cite and link to, when possible, the SI Website as the source of the Content.
- You may not remove any copyright, trademark, or other proprietary notices including attribution information, credits, and notices, that are placed in or near the text, images, or data.
- You must comply with all terms or restrictions other than copyright (such as trademark, publicity and privacy rights, or contractual restrictions) as may be specified in the metadata or as may otherwise apply to the Content.

The Smithsonian does not use Creative Commons licenses to share the 3D models or digital design files that they have created, choosing instead to release these assets on the basis of copyright's fair use doctrine (U.S. Copyright Act, 1976). This doctrine, as specified in Section 107 of the Copyright Act allows an individual to use copyrighted material without acquiring permission from a copyright holder for use under certain conditions, which in this case is specified as personal, educational and non-commercial use.

6.2.5 Analyzing the cultural nuances of intellectual property

Even when an artifact's digital model cannot be made publicly available for downloading, there are other ways that Kevin's institution has leveraged this data to make an artifact more accessible to the broader public. An example of this is the Tlingit Whale Hat, which is a sacred object that was in the institution's collection, but was scheduled to be repatriated to the Tlingit clan in Alaska (Solly, 2017). Repatriation in the context of museums is the returning of an object or artifact to a community, group or culture to which it belongs. It is often used to describe the process of returning objects to tribal and Native American communities from which these artifacts were taken in an unauthorized manner. "The Native American Graves Protection and Repatriation Act (Public Law 101-601; 25 U.S.C. 3001-3013) describes the rights of Native American lineal descendants, Indian tribes, and Native Hawaiian organizations with respect to the treatment, repatriation, and disposition of Native American human remains, funerary objects, sacred objects, and objects of cultural patrimony, referred to collectively in the statute as cultural items, with which they can show a relationship of lineal descent or cultural affiliation. One major purpose of this statute (Sections 5-7) is to require that Federal agencies and museums receiving Federal funds inventory holdings of Native American human remains and funerary objects and provide written summaries of other cultural items" (National Park Service, 1990).

The Tlingit Whale Hat encompasses the ancestors of the clan and allows members of the tribe to feel their presence (Solly, 2017). The repatriation process for the Hat was accelerated due to the critical illness of the elder who was set to receive it. The Hat was delivered to the elder right before he passed away, which was incredibly meaningful for the Tlingit clan. The new leader of the clan who oversaw the clan's sacred objects on behalf of the community developed a long-standing relationship with one of the anthropologists which helped to facilitate the repatriation of the Hat, so much so that the leader decided that the Hat could be temporarily returned to the Smithsonian to be digitized so that it could be added to the 3D collection. This was a historic event- no artifact that has been repatriated has ever come back to the institution. Great lengths were taken in the effort to transport the Hat back to the institution for this process. Because the Hat had been returned to the clan, only the clan leader could handle the Hat, so he was present throughout the scanning and digitization process. "Digitization experts laser-scanned the hat, bouncing a beam off of its surface and deriving measurements from the time it took the laser to bounce back, and also collected 3D data through an imaging technique called photogrammetry" (Solly, 2017). "Photogrammetry focuses on extracting 3D information from photographs. The process involves taking overlapping photographs of an object, structure, or space, and converting them into 2D or 3D digital models" (Autodesk, 2019).

While the digital model could not be made available for download to the general public, the Tlingit clan permitted the institution to take the digital model and create a CNC milled replica of the Hat for educational purposes. The replica is on display at a museum. The 3D model of the Hat can also be found on the Smithsonian 3D online repository. Individuals can view the 3D model of the Hat in detail using the 3D model viewer and learn more about the historical and cultural significance of this artifact. The process of scanning and digitizing the Hat and creating the replica took place over the course of two years.

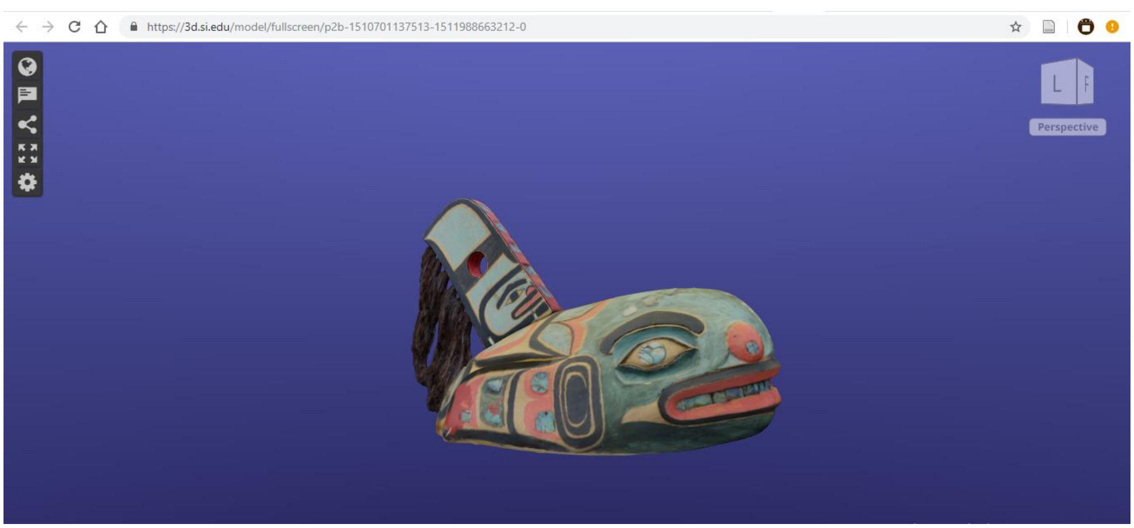

Figure 4: Tlingit Whale Hat model on Smithsonian 3D online platform.

This has provided an opportunity for the public to view the replica of the Tlingit Whale Hat and learn about the Hat's significance while the original remains with its rightful owners. As part of the agreement between the Tlingit Clan and the institution, when members of the clan are in town, they have the right to use the replica of the Hat for ceremonial dances and tribal gatherings, which they have done in the past (Solly, 2017).

What happens when the object of the digital model that is created belongs to a community or group of people for whom IP law does not provide a meaningful concept, align with their culture and values or is not recognized altogether? For the Tlingit people, sacred objects like the Whale Hat belong to the whole community, not to one person (Solly, 2017). The notion of “cultural property” has been introduced in the legal domain to describe situations in which an object belongs to a community, group or culture (UNESDOC, 1954). Cultural property has also been discussed in relation to indigenous intellectual property, which attempts to specifically provide protection for the culture and heritage of indigenous and tribal communities given numerous instances in which nations have had trouble determining how their laws apply in conjunction with tribal laws and norms (Commission on Human Rights Sub-Commission of Prevention of Discrimination and Protection of Minorities Working Group on Indigenous Populations, 1993). There are numerous examples of the ways that individuals, organizations and companies have engaged in cultural appropriation in negative and morally offensive ways. The Smithsonian must maintain a balance between being a steward for objects that possess specific historical, cultural and social value while also striving to broadly share the knowledge that it acquires. This is a governance process that has been developed through a set of norms that have been established internally within the institution and between the institution and the museums it works with to ensure that sharing and distribution of knowledge and data is done as openly as possible while respecting cultural values.

Figure 5: Replica of Tlingit Whale Hat. Photo credit: James DiLoreto

6.2.6 Fostering the conditions to facilitate the use of 3D models beyond 3D printing

The case of the Tlingit Whale Hat surfaces how 3D models can be used to create 3D printed objects, but they can also be used to create physical objects using other technologies that can also use these files like CNC milling machines or laser cutters. 3D models can also be integrated into other digital environments such as virtual reality, augmented reality or e-books.

The efforts that Kevin's team is taking to develop a 3D metadata model and accompanying tools to optimize the digitization and 3D modeling processes is illustrative of the ongoing discussions and steps in organizations that work with 3D data. It includes the development and maintenance of a cyberinfrastructure that ensures that the generated 3D data is standardized, secure and accessible as well as compatible with various applications, platforms and technologies with which the 3D data and models are used now and in the future. File formats for 3D data are not new; the technology for creating digital models was developed in the late 1950 and early 1960s (Mchenry & Bajcsy, 2008). Computer-aided design (CAD) first focused on creating 2D models and eventually enabled individuals to generate models of 3D objects. In the beginning, the technology for creating 3D models was primarily accessible to technologists, researchers and industry. Companies began to package and sell their own versions of CAD software that could be used on PCs in the 1980s. Today, individuals have a broad range of commercial and free software options such as Autodesk Inventor, Blender and Sketchup (Chakravorty, 2019). With so many different companies producing 3D modeling software, many companies use proprietary data formats, which has made interoperability and standardization a challenge. This modeling software can be used to create models specifically for 3D printing, but is widely used to create 3D models for other purposes such as designing digital games, movies, animation and scientific research. To date, there are hundreds of different 3D file formats, many that are proprietary and some that are open source (Mchenry & Bajcsy, 2008). While STL files are the most common file format specifically for 3D models designed to be used for 3D printing, many organizations aim to develop collections of 3D data that can be used for different applications- this could include 3D printing, but can also include for use in films, VR, AR and digital games.

As a result, organizations are engaging in sector-specific conversations about how to develop a model of data stewardship that best fits the needs of their field currently and into the future.

An example of this is a project funded by the Institute for Museum and Library Services, Community Standards for 3D Data Preservation (CS3DP), which aims “to bring together stakeholders to work toward establishing shared standards, practices, and technologies for digital

3D data preservation, documentation, and dissemination” (Washington University, 2017) The project is being led by Anthropology and Research & Instruction librarians at Washington University in St. Louis and the University of Iowa respectively, along with a team at the University of Michigan Museum of Paleontology (Washington University, 2017).

“The initial stage in infrastructure formation is system-building, characterized by the deliberate and successful design of technology-based services. Next, technology transfer across domains and locations results in variations on the original design, as well as the emergence of competing systems. Infrastructures typically form only when these various systems merge, in a process of consolidation characterized by gateways that allow dissimilar systems to be linked into networks” (Paul N. Edwards, Steven J. Jackson, Geoffrey C. Bowker, & Cory P. Knobel, 2007). Therefore, infrastructure is not just about technological systems, but it is about the assemblage of people, organizations, values, processes and policies that come together towards a shared objective, fueled by technological development (Bowker, Baker, Millerand, & Ribes, 2009; Gibbons et al., 1994; Jackson, Edwards, Bowker, & Knobel, 2007; Paul N. Edwards et al., 2007).

6.2.7 Integrating relevant social groups into the design and development process of 3D digital tools

The development process of the open source tools for 3D digitization and modeling that Kevin and his team are working on and the role of users and relevant social groups in these processes and activities can be further illuminated through the Social Construction of Technology (SCOT) (Bijker & Pinch, 1989; Pinch, 1992). Through SCOT, one develops a deeper understanding of the critical role that individuals or groups of people play by identifying their own unmet needs, actively contributing to the design of a technological artifact that addresses these challenges, thus engaging in “interpretive flexibility” (Bijker & Pinch, 1989; Pinch, 1992).

Throughout the development process, Kevin’s team is interacting with future users of these tools, relevant social groups, who are actively contributing to the creation of specific features that will make the tools useful for a broad range of applications. Relevant social groups are important because each group has a unique relationship to a particular technological artifact and provides insights into different ways in which a technology might be utilized and innovated upon based on the needs and perspectives of that particular group (Bijker & Pinch, 1989; Kline & Pinch, 1996; Oudshoorn et al., 2004).

One such group is K-12 educators who are actively using 3D modeling and printing to provide students with more hands-on, tangible learning experiences related to math, science, engineering and the arts in the classroom and in after school programs in libraries, museums and community centers. These educators have developed projects where students are creating 3D models to demonstrate their geometry knowledge, using 3D printing to create parts for invention prototypes and 3D modeling and printing less known but significant figures in U.S. history. Like every relevant social group, these educators possess a particular “technological frame;” a shared perspective that members of the same relevant social group have about the technological artifact, its capabilities and limitations, how it can be used and its value and role in society more broadly. It is important to acknowledge that technological frames are not static. They can evolve over time based on the acquisition of new knowledge or changing beliefs triggered by certain developments. This concept of the technological frame, first described by Bijker and then elaborated upon by Orlikowski and Gash is helpful here because it describes why particular groups may have distinctly different perspectives on the capabilities, applications and roles of a technology that directly inform how these technologies will be developed and used by these groups (Bijker & Pinch, 1989; Orlikowski & Gash, 1994). Bijker articulates that "A technological frame is composed of, to start with, the concepts and techniques employed by a community in its problem solving" (Bijker, 1989). Furthermore, the technological frame of a particular group is what informs the shared meaning and significance of the technology relative to that group. Such interpretations of technology are central to understanding technological development, use, and change in organizations as they critically influence the way people act around technology" (Orlikowski & Gash, 1994).

Working with different groups of users enables the team to identify unexpected and unanticipated uses of the technologies they develop and the 3D models that they create. SCOT recognizes that users have agency and play a significant role in driving the development of technologies (Bijker & Pinch, 1989; Oudshoorn et al., 2004). By making these tools open source and widely available for the public to use, relevant social groups can more easily access these technologies, contribute to their development and modify the technologies themselves, while providing useful feedback to its original creators. Through the process described through the social construction of technology, relevant social groups are actively involved in three distinctive processes- interpretive flexibility, closure and stabilization (Kline & Pinch, 1996; Lindsay et al., 2005). A relevant social group engages in interpretive flexibility by developing its own understanding of how a technological artifact can be useful and how this technology can be modified to address specific needs shared by these groups. This leads to the multi-directional model of technological development that Pinch and Bijker describe in which a technology is modified in different ways by different relevant social groups, resulting in multiple versions of a technological artifact. Access to a technological artifact is a critical factor with regards to how relevant social groups are truly able to actively engage with a technology. 3D printing is one such example. Efforts to open source the tools for 3D digitization, 3D modeling and 3D printing creates opportunities for a larger number of relevant social groups to be able to engage in interpretive flexibility. Relevant social groups are also porous. Individuals can be part of one or more relevant social groups at any given time or develop modifications to a technology that could be helpful to a relevant social group that they may not specifically be part of. Such was the case when a Japanese toy designer and artist downloaded the 3D model of a woolly mammoth that Kevin's team had made available through the online repository. The toy designer thought that the model could be a great educational tool, but realized that the extremely hi-resolution model provided on the platform would be difficult for teachers and students to use on a desktop 3D printer. He took the original file, compressed it by 95% and made additional adjustments to the model, such as adding support structures to areas that would most likely break during the printing process, like the rib joints and the toes. The toy designer also added articulated joints, which meant that students could pose the woolly mammoth in different positions.

The large and global online community of individuals using 3D modeling and 3D printing across different fields means that there could be numerous relevant social groups beyond the GLAM sector that Kevin's institute operates within, each with their own process of engaging with the technology to reach stability.

6.3 Case Study 3: A recursive public e-NABLEing the widespread use of 3D printing for low-cost prosthetics

This case study explains the important role that a recursive public can play in fostering an environment to enable the development and distribution of low-cost, 3D printed prosthetics globally. The recursive public enables its members to manufacture and distribute these innovations largely outside of the commercial market to reach those who need these solutions the most, but are not being served because they cannot afford them or do not have access to traditional medical institutions or organizations where prosthetics are available.

In 2013, a video of a 5-year old boy named Liam wearing a 3D printed upper-arm prosthetic posted on YouTube went viral (HodgePunk, 2013). The video showed Liam gleefully picking up various items, such as a bottle of sunblock, a basketball and a small coin, demonstrating the dexterity he was able to achieve with what was a low-cost, homemade, DIY assistive technology. The prosthetic was the brainchild of Richard Van As, a carpenter from South Africa and U.S.-based Ivan Owen, a maker, special effects artist and puppeteer. Van As originally connected with Owen after Van As lost the use of multiple fingers on his right hand due to an accident with a table saw and could not afford to purchase an industrial prosthetic. After seeing a video online where Owen was demonstrating a puppet hand that he had built with fingers that could move through the use of thin steel cables, Van As reached out to Owen to inquire about whether he might be able to help him (Gallagher, 2013). The resulting collaboration led to a prototype of a low-cost upper arm prosthetic that could be used by individuals that had limited use of their hands and/or fingers. This early version of the hand was not built using 3D modeling and 3D printing, but rather, a combination of different materials, including metal and textiles. Shortly after, Owen and Van As developed a version of the prosthetic that could be 3D printed. They called it the Robohand, and uploaded the files to Thingiverse.com (Robohand, 2014).

6.3.1 Catalyzing a global network with a YouTube video comment

One person who watched the YouTube video with Liam was a professor in Upstate New York who wondered about what was possible now that the design was freely available for anyone around the world to use. As he reviewed the comments posted by individuals, he noticed that there were quite a few people that expressed a desire to do something similar, either because they knew of someone who could benefit from such a device or they had the skills, resources and equipment to be able to produce such a device. Nick*[3] describes, "I created a Google Maps mash-up on a whim that morning and I put my own post into that comment stream and it said: "ok makers, if you know someone that needs a hand, put a pin on this map and if you have a 3D printer and you want to help, put a pin on this map." It was really a thought experiment, except that it was public and global. And as the YouTube video went viral, more people started putting pins on the map. There were seven that night, seventy in six weeks and people started calling me and saying, what do we do next?"(Nick, 2019).

Nick admitted that he had no idea what to do next. He did not have a fully developed plan, but recognized the value of figuring this out in collaboration with the thousands of people who had expressed a desire to get involved. His first step was to create a Google + community (a common social media platform) which today has more than 11,000 people (Nick, 2019). Prior to this, Nick had not had any real experience with 3D printing. The university where he worked had 3D

[3] Name has been changed for the purposes of anonymization

printers in specific departments, but Nick never used them. But he believed in the potential of the technology to democratize access to prosthetics to a vast number of people around the world, particularly those who had no other options.

6.3.2 Experimenting with structures and processes to coordinate volunteer activity

Nick describes the development of the community and organization as an evolution that consisted of different phases. Each phase attempted to create an infrastructure to organize people so that they could effectively work together and develop a set of processes, policies and norms that would enable the group to function. It describes the emergence, growth and maintenance of a "recursive public," aimed at developing and distributing low-cost, open source, 3D printable prosthetics to people around the world that needed them. Kelty articulates that "[r]ecursive publics, and publics generally, differ from interest groups, corporations, unions, professions, churches, and other forms of organization because of their focus on the radical technological modifiability of their own terms of existence" (Kelty, 2005). One observes that the grass-roots nature of the community, its geographical distribution, significant reliance on the Internet and Internet-based software and platforms necessitated the creation of a recursive public in order to enable this group to carry out their mission in ways that would have been significantly more difficult or perhaps impossible within the kinds of structures, hierarchies and policies of more traditional organizations.

Nick articulates that initially he and other colleagues who co-led the project, had to learn through the process of trying and making mistakes, what approaches and mechanisms would create an environment in which there was enough centralization to coordinate activities across the world and provide the necessary "connective tissue," but empower local groups of volunteers with the autonomy and independence to act in a decentralized manner (Nick, 2019).

After Nick created the map and the Google + community, he incorrectly assumed that people would take the initiative to match themselves up using the information provided by these resources, but this was not the case. In response, Nick developed a process to broker these matches by asking individuals to fill out an online form which contained specific questions about an individual's needs, skills and resources. A small committee was formed which helped to review, monitor and assign tasks.

6.3.3 Using Creative Commons licenses to distribute design files for the prosthetics

Working asynchronously and with members geographically distributed around the world, the community leveraged the initial open source designs for the Robohand to then over time develop a series of 12 additional 3D-printable upper limb assistive devices, the digital design files of which have been released using a variety of different CC licenses (Enabling The Future, 2019). The table below details each e-NABLE prosthetic design and the specific CC license that it has been assigned.

Name of e-NABLE prosthetic design	**Creative Commons License Used**
Phoenix v2	Creative Commons - Attribution - Non-Commercial - Share Alike
Unlimbited Phoenix	Creative Commons - Attribution - Non-Commercial
Phoenix Reborn	Creative Commons-Attribution
Raptor Reloaded	Creative Commons - Attribution - Non-Commercial
Osprey Hand	Creative Commons - Public Domain Dedication
Talon Hand 2.0	Creative Commons - Public Domain Dedication
Cyborg Beast	Creative Commons-Attribution-Non-Commercial
Ody Hand	Creative Commons - Public Domain Dedication
Flexy Hand 2.0	Creative Commons - Attribution - Non-Commercial - Share Alike
The UnLimbited Arm v2.1 - Alfie Edition	Creative Commons - Attribution - Non-Commercial - Share Alike
Gripper Thumb Terminal Device (as part of Adjustowrap Gripper Arm System)	Creative Commons-Attribution
RIT Arm	Creative Commons-Attribution

Table 3: Creative Commons licenses used by e-NABLE prosthetic designs.

The designs for these devices provided more customized solutions for individuals with different kinds of upper limb differences (Flaubert, Spicer, & Jette, 2017). For example, some of the designs are for people who have a functioning wrist but are missing fingers, while other designs fit the needs of someone who does not have a functioning wrist or palm, but can bend their elbow (Enabling The Future, 2019). 90% of the individuals participating in the group are volunteers who iterate on the designs for these assistive devices and helping to broker matches between those who can custom fit and 3D print a prosthetic with someone who needs one.

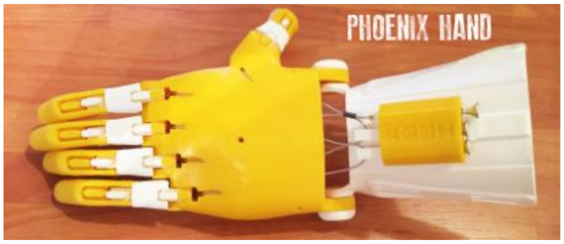

Figure 6: Example of an upper limb prosthetic for individuals with a functional wrist and a full or partial palm. Source: enablingthefuture.org

Figure 7: Example of an upper limb prosthetic for an individual who does not have a functional wrist or a palm. Source: enablingthefuture.org

In 2015, the group reached a growth milestone when Google.org gave them $600,000 as part of a $20 million initiative called The Google Impact Challenge: Disabilities (Google.org, 2019). While Nick believed that part of this funding could be really helpful if it was used towards initiatives to foster community growth and development, Google.org made it clear that it wanted this funding to be fully used to create a matching and tracking system, a site that would automate the screening process and streamline the steps needed to provide someone with a prosthetic (Google.org, 2019). Yet such a platform could only be functional if the community was organized in such a way that they would actively use such a tool and it was still unclear as to what this organizational model should look like. These critical questions aside, the group knew that it would need to form a non-profit organization, known in the United States as 501(c)(3) in order to receive the funding from Google.org. Nick and several key members of the community made the decision to apply for formal 501(c)(3) status and create the Enable Community Foundation.

6.3.4 Establishing the community as the Enable Community Foundation

In creating the Foundation, a Board of Directors had to be formed and a CEO needed to be selected. By choosing to become a 501(c)(3), those individuals leading this community were making a decision that would ultimately dictate who would have power to make decisions, how this power would be distributed and the ways in which the work was carried out. In an effort to bring in leadership whose experience was aligned with the mission of the organization, the CEO was a former Assistant Attorney General who had helped to get the Americans with Disabilities Act passed in 1990. The creation of this new, more traditional organizational infrastructure where power and oversight were centralized was not well received by the broader community. Nick reflects "It turns out that traditional non-profits have a manifest destiny to become traditional institutional organizations. The e-NABLE community was not that. They did not take kindly to centralized control and centralized oversight and indeed the foundation (CEO and Board of Directors) did not know how to handle this distributed laissez faire community" (Nick, 2019).

This resulted in a genuine rift between the community of volunteers and the Foundation leadership. The Foundation was increasingly uncomfortable with what they perceived to be as a large group of untrained, non-professional volunteers performing what some might consider medical procedures (designing and fitting prosthetics) without more oversight. A large part of this had to do with the fact that traditionally, the development of prosthetics and their availability on the market in the U.S. and other developed countries are governed by standards and regulations. These standards are developed by international organizations and agencies such as the International Society for Prosthetics and Orthotics (ISPO), the World Health Organization (WHO) and the U.S. Agency for International Development. In 2017, these organizations partnered together to develop global standards for prosthetics and orthotics, which "advocate for the integration of prosthetics and orthotics services into health services, under universal health coverage. Implementation of these standards will support countries to fulfill their obligations under the Convention on the Rights of Persons with Disabilities and towards the Sustainable Development Goals, in particular Goal 3: Ensure healthy lives and promote well-being for all at all ages" (World Health Organization, International Society for Prosthetics and Orthotics, & U.S. Agency for International Development, 2017).These standards cover areas that range from the kinds of materials that can be used for prosthetics to the training of prosthetic professionals and distribution of the devices. These standards are also aligned with those developed by the International Standardization Organization (ISO) around prostheses and orthoses (ISO, 2006, 2008, 2013).

Depending on who you speak with within the fields of prosthetics, assistive technologies and humanitarian work, there are individuals who feel strongly that the standards developed ensure that those who are differently abled are using the safest, most high-quality prosthetics available. Others understand the need for standards and regulations but articulate that these standards, which are developed primarily by Western based organizations where high-end materials and cutting-edge technologies for producing prosthetics are more widely available, do not take into account the specific social, economic and cultural contexts of other cultures.

The CEO and Board believed that a more cautious approach should be taken, questioning the ability for this geographically distributed group of volunteers to safely and effectively design, build and fit these upper limb prosthetics. In their view, the process of designing and fitting prosthetics should be undertaken by professionals with formal training. The U.S. Bureau of Labor Statistics describes, “Prosthetists are specifically trained to work with prostheses, such as artificial limbs and other body parts. Some orthotists and prosthetists construct devices for their patients. Others supervise the construction of the orthotic or prosthetic devices by medical appliance technicians” (U.S. Bureau of Labor Statistics, 2018).

The perspective of Nick and many of the other volunteers is that while they may not be professional prosthetists, their global network is providing services which are better than the alternative for many people, which in many cases can be nothing at all. In some countries, there is a massive need for upper limb prosthetics, but very few or no professional prosthetists. Sierra Leone currently has one prosthetist, for the entire country. And if by chance a patient is lucky enough to be able to access the services of a prosthetist, the costs of these prosthetics are often cost prohibitive.

6.3.5 Recognizing the need for a different organizational structure to continue community-driven innovation

Over time, the tensions between the community and the Foundation leadership team were so severe that the Foundation made the decision to step back from working with the community. This meant that they would no longer support the efforts of the volunteers who made this global initiative possible in the first place. In doing this, the Foundation effectively changed its focus, choosing to concentrate on providing clinicians and other health professionals with the tools, designs and resources to more easily create 3D printed prosthetics. Rather than embracing the collaborative free innovation taking place, the Foundation weighed the safety and health risks involved in this more open approach to designing prosthetics and determined that it should pivot to a model that was aligned with what the traditional prosthetics industry and medical professionals were used to.

In making this decision, the Foundation overlooked several crucial aspects. They underestimated the relevant skills and experiences that the volunteers had. The volunteers may not have been professional prosthetists, but many of them had backgrounds in engineering and product design, subject areas that are valuable to designing and improving upon these devices. The volunteers were not designing these prosthetics in a vacuum. Volunteers in a specific geographic region formed partnerships with local clinics and medical centers which provided care and support for differently abled individuals that could benefit from these devices, developing working relationships with clinicians and prosthetists. This meant that even if the volunteers themselves did not always have the medical experience or background, they did have access to a cadre of experts who could contribute their knowledge to the design and fitting process.

When the CEO and the Board decided to change directions, Nick made the decision to resign from his role at the Foundation, where he had served on the Board and had been receiving some funding via the grant from Google.org. With this split in 2016, the e-NABLE Community of volunteers lost its Google.org funding, which remained with the Foundation. Since 2016, the Community has reconfigured the way that it is organized in a manner that supports its grass-roots philosophy so that it can continue its original mission of providing low-cost 3D printed prosthetics to those who need them the most. One of the most significant realizations was the fact that the entire Community did not need to be configured as a traditional non-profit organization in order to continue to grow and achieve its mission of providing low-cost, open source 3D printed prosthetics to people who needed them. In fact, the centralized structure, hierarchical decision making and obligations to large scale funders seemed to stunt if not hinder the progress of this international community.

Volunteers are now organized by chapters, with each chapter having its own autonomy. To date, there are 100 chapters in 55 countries (Nick, 2019). This provides volunteers with the opportunity to work in smaller, more flexible groups and teams. Teams can be configured for a specific project, then disbanded and reconfigured for another project and individuals can work with those in their own chapter or across chapters. Nick's belief in the value and impact of the Community has led him and several colleagues to continue to pursue models for mobilizing volunteers that seek to empower them locally within their own communities. Drawing from research and learnings about the dynamics of earlier online communities, Nick and key members of the Community have created an infrastructure that provides each member of the Community with the opportunity to be heard and weigh in on important decisions while maintaining a level of oversight. Nick notes, "...we have just enough connective tissue to preserve as much of the movement as a movement, but not a centralized organization. We are now trying to figure out how to strengthen a global configuration of autonomous chapters of this sort" (Nick, 2019).

Another significant learning in the misalignment of the organizational structure and leadership team with the group of individuals they were supposed to support and empower was the fact that the work of the Community does not inherently require significant infusions of funding like a non-profit organization typically needs. This is not to say that the Community would not benefit from receiving funding to further support their efforts, but that at its core, it is a grass-roots volunteer run organization which is what enables them to reach people and work in places and contexts that larger, more bureaucratic organizations would not be able to go. Nick asserts, "What is shown is that there is a system that supports money, to the extent that money flows, but I would say that 90% of what e-NABLE does is through volunteers. We have a governance system that people can use to get things done that they can't or don't want to do on their own and that includes me."

These are collaborative free innovators who are not motivated by money, but rather, the prospect of helping others by developing assistive technologies that could significantly improve their lives. The thinking around what the e-NABLE Community of volunteers does has also evolved over the years and they now describe themselves as "connected humanitarians." Nick describes how traditional non-profits depend on donors and need to do things in a way that donors are comfortable with and this constrains what they can do. Traditional organizations like businesses, non-profits, governments and NGOs each have a model that is privy to market demands, which in many cases can be to the detriment of their original mission. Nick reinforces, "We are able to reach people who remained underserved. We can go places that they can't go. I see the e-NABLE Community as a prototype of connective tissue for existing organizations- trying to develop this 4th leg for the stool which could greatly reduce the number of people who remain unhelped by traditional institutions" (Nick, 2019).

6.3.6 Supporting the recursive public through a technological infrastructure

"Recursive publics are publics concerned with the ability to build, control, modify, and maintain the infrastructure that allows them to come into being in the first place and which, in turn, constitutes their everyday practical commitments and the identities of the participants as creative and autonomous individuals" (Kelty, 2005). The Community is very clear that it is not a traditional organization. On its official website, it describes itself as "a network, not an organization. But it is organized. Sort of." The Community is a recursive public and the process, tensions and developments describe the various efforts and struggles that were required to create an infrastructure that would continue to enable them to exist and function across geographies and cultures. This includes a self-grounding approach which is centered around establishing the necessary layers of technical and legal infrastructure to achieve its mission and further enable others to be part of the recursive public (Kelty, 2005). The Community has developed a centralized online system where volunteers can stay up to date on projects, document the progress they are making on the projects that they are working on and participate in key decision-making processes. Availability of data and transparency are two priorities and core components of this technical infrastructure. A separate area of the centralized platform, called the Atlas, maps the way that individuals within the network work together, describing committees and teams that work on specific topics such as education. The Atlas is built using Kumu, a web-based tool designed to map and visualize relationships between different data points (e-NABLE, 2019b). The Atlas consists of multiple layers, such as the Network: Core-Plus layer, which describes how specific individuals, committees and communication vehicles (websites, newsletters, social media platforms) interact with one another. The Network: Core-Plus layer is shown in Figure 8. When a user rolls over one of the colored nodes in the network, a more detailed description of the role of that particular entity is provided. In Figure 9, one can see how the Enablio platform is where members of the e-NABLE Community review and vote on proposals and other critical decisions.

After separating from the Foundation, the Community established another 501(c)(3) not-for-profit structure (included in Figure 8 as Rochester Enabled Limited) in order to be able to accept financial gifts. The modest amount of money that has been received by the Community goes into a fund which is used to support a mini-grants program. Volunteers working on projects across different chapters can submit mini-grant proposals, which include a description of work to be performed, expected results and impact, an estimate of required work hours, an estimated timeline for completion of the effort, and the amount of requested funding. Proposals are made available for the Community to review on a monthly basis and Community members are invited to vote on proposals on Enablio. Enablio is a distributed decision making tool powered by the web-based software Loomio (Loomio, 2019). Nick and other leaders within the Community collectively came up with the policy that if a proposal gets 15 or more votes and 80% of those votes are favorable, the proposal will be approved and funding granted. Nick admits that this system is not error proof. There is the possibility that members could game the system by voting more than once, but he articulates that there is a certain level of trust that has been established within the community around the collective work that they are doing and thus far they have not identified any foul play in this respect.

Enablio is connected to the Strategic Planning Committee, which uploads the proposals for review to the platform and the EnableFund, which provides the funding for proposals which require funding. Collectively, the different layers of the Atlas detail the main communication vehicles, organizational structures (i.e. 501(c)(3)s, committees, and technologies that in combination, create the infrastructure that allows the Community to do this work.

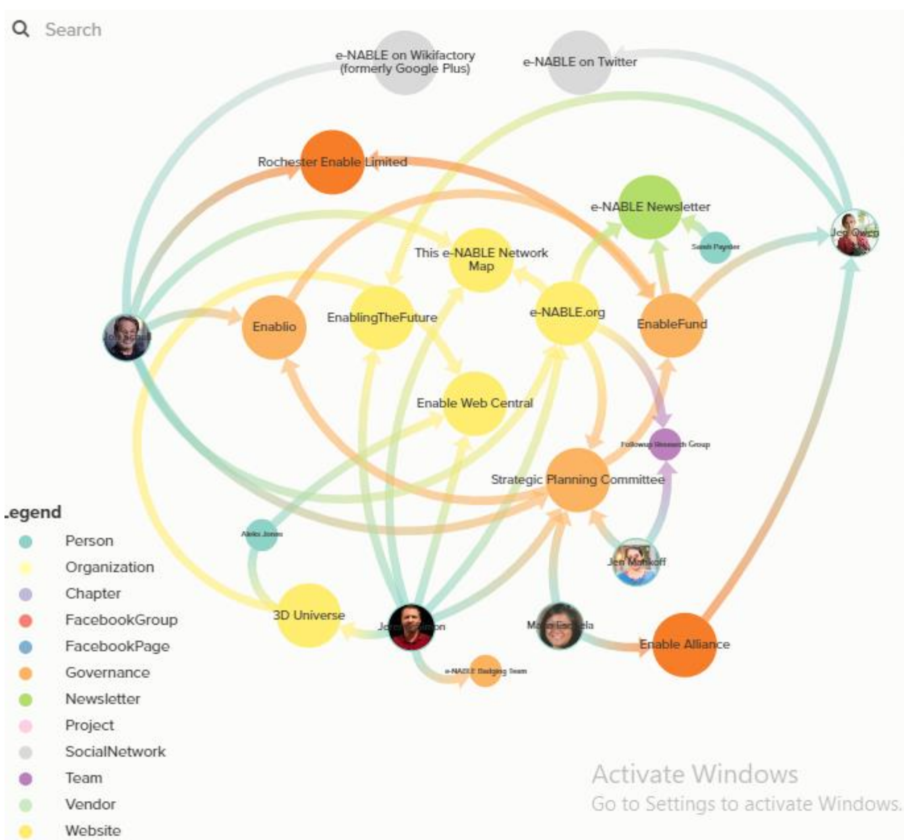

Figure 8: Network Core-Plus layer of the e-NABLE Atlas. Source: e-nable.org

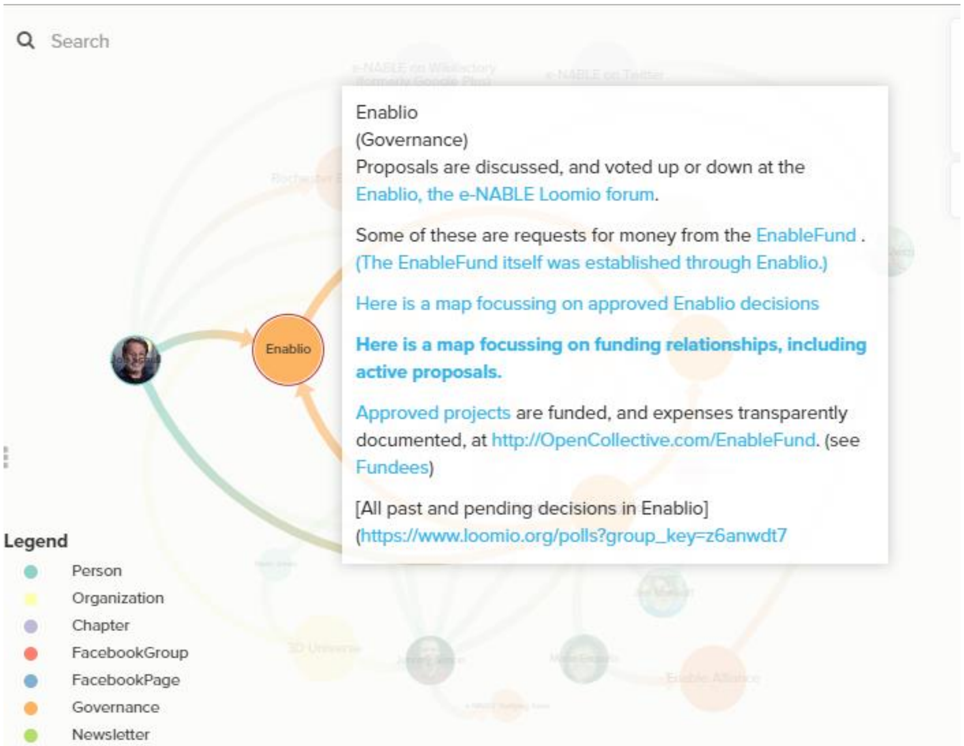

Figure 9: Enablio detailed description on the e-NABLE Atlas. Source: e-nable.org

6.3.7 Reorienting power and knowledge through processes promoting availability and modifiability

Nick and several other leaders developed a social infrastructure that maps the technical infrastructure and organizes thousands of people who are part of the Community in such a form that allows a subgroup to facilitate and orchestrate activities in an effective, coordinated way. Each week a strategic planning committee of four people participate in a video conference. Nick describes this as a “small, powerless group” which includes himself, the main developer and maintainer of the online platform and the main Community moderator. There is no exclusive rule about who can be a part of the strategic planning committee, which means that other members are welcome to join as long as they are committed to attending and participating in these meetings regularly. This group discusses key priorities and ongoing projects. These sessions are recorded and made available to the Community to engage in discussion about online.

One core concept central to recursive publics is that they engage in the “reorientation of power and knowledge” through availability and modifiability (Kelty, 2005). Availability includes things like transparency, open governance or transparent organization, secrecy and freedom of information and open access in science (Kelty, 2005). Transparency, visibility and availability of data is essential to the e-NABLE Community’s work and its ability to function as a loosely organized network. This is also central to the notion that the perspective and contributions of every Community member are valued and that there must be mechanisms in place that enable members to learn from one another and have access to the data necessary to make decisions. Complementary to availability is modifiability, which includes the ability to access and reuse something unrestricted to create new innovations, use a technological artifact in question for new applications or in new contexts (Kelty, 2005). The clearest example of this is the extent to which the Community has shared the digital design files, the assembly instructions and accompanying tutorials for each of the ten 3D printable upper limb devices that they’ve developed. Because these devices are assistive technologies that need to be customized based on the physiologies and needs of each individual, the Community has taken extra care to ensure that they provide as much detailed information as possible to inform the process of identifying the best design for a particular individual. This includes a “Which Design?” guide which walks an individual through a series of steps and criteria to make this match (Enabling The Future, 2019).

Nick and others within the Community have been very public about the ongoing efforts to create an infrastructure for their network. Several key excerpts from an article written in 2018 by Nick describe how the recursive public continues to take shape, evolve and grow:

> "The traditional organizational response to growth is to develop hierarchical authority structures…and become a traditional organization. We tried that once; we might try it again. But maybe…and this is what I am most excited about…maybe we can thrive by embracing the fact that we are not a traditional organization….e-NABLE is now a network, not just of passionate individuals, but of "chapters" in over 80 countries. Chapters are large enough to make a real difference, but small enough to empower individual members, cultivate mentors and leaders, and organize themselves as they see fit. Because they are localized and diverse, chapters can develop locally appropriate solutions and specialties. And with the right infrastructure of "internet communications, 3D printing, and good will," chapters can complement each other and share stories, solutions and values. So what kind of infrastructure do we need? One that supports and develops autonomous chapters unified by shared values and shared designs while supporting collaboration, innovation, sustainability, and collective intelligence among individuals and chapters"(Schull, 2018).

6.4 Collective Analysis of Case Studies

Recall that these three case studies focused on the work of Field Ready, The Smithsonian and e-NABLE and were chosen because they provided the opportunity to further examine: 1) how 3D printing users make decisions about whether to use CC licenses; 2) alternative approaches users take when they do not use CC licenses to share their work; and 3) an investigation of the significant factors and conditions that affect whether a user decides to share or not share digital design files. The case studies also further illuminate unexpected findings resulting from the analysis of the initial interviews about how field-specific challenges, policies and norms can play critical roles in determining a) how 3D digital design files are distributed; b) the role that IP plays in accelerating advancement of 3D printing through the tools and software that make 3D printing possible and; c) the importance of organizing the community of 3D printing users in a manner that is conducive to collaboration, sharing and utilization of the assets that they have developed.

6.4.1 Risk as a mitigating factor for sharing digital design files

The case studies provided an overview of how these organizations utilize 3D digital designs in the humanitarian field (Field Ready), the galleries, libraries, archives, museums (GLAM) field and assistive technologies field (e-NABLE).

In all three cases, risk plays a critical role as a determining factor for whether a digital design file of an object is shared. With Field Ready, risk is defined by concerns around safety. Do the individuals who download the files have the experience, skills and resources to be able to print the file as specified? For the Smithsonian, risk is informed by the possibility that individuals might misuse the models of historical and cultural artifacts in ways that may be offensive, culturally insensitive or morally questionable. When the decision to share an artifact online in the form of a 3D model has been made, one major challenge for the Smithsonian is figuring out how to communicate the historical, cultural and social significance of an artifact digitally. e-NABLE's risk is related to the standards and regulations that have historically governed the assistive technologies space, more specifically the prosthetics industry. e-NABLE has experienced tensions that have to do with its non-traditional approach to developing, producing and distributing low-cost prosthetics in a field driven by longstanding medical and healthcare institutions and prosthetic manufacturers who are concerned that volunteers within the e-NABLE community do not have the skills, background or experience to effectively design and fit patients.

Regarding IP, the cases shed light on the ways that Creative Commons licenses can be used to facilitate sharing, but this is just one of a number of different mechanisms that organizations use in the process of distributing the digital designs that they have created. Field Ready and e-NABLE use CC licensing, while the digital design files released by the Smithsonian are governed by the fair use doctrine of U.S. copyright law.

There are still a number of outstanding questions for 3D printing users about how CC licenses protect digital designs and how such protections extend to the physical, 3D printed objects that are created from these designs. For digital designs which are functional devices, such as the solutions developed by Field Ready and the technologies created by e-NABLE, the creative elements of a solution would be protectable by copyright and by extension the CC license. Because of the doctrine of separability, functional elements of a design could require patent protection. In all the interviews conducted I did not speak with a 3D printing user who sought both copyright and patent protections for the digital designs files they created. If they chose to utilize CC licenses, they applied the license across the entirety of a digital design. Subsequent legal cases will inform the extent to which both creative and utilitarian elements of a 3D digital design will apply to copyright law and CC licenses.

Historical cases and legal precedence indicate that the debate about IP protection related to 3D digital designs and their accompanying objects is concentrated on copyright and focused more specifically on the digital designs of these objects. Recall that a 2017 case that was not specifically about 3D models could actually impact the ways in which U.S. copyright laws will apply to digital design. In Star Athletica v. Varsity Brands, the Supreme Court ruled that the designs of cheerleading uniforms could be copyrighted (Mullin, 2017). This was on the basis that creative elements of such uniforms (which are copyrightable) could be separated from utilitarian aspects (which are not copyrightable). Using this case as legal precedence, one could assert that for organizations such as e-NABLE and Field Ready, specific creative elements of a 3D digital design apply to a CC license while the utilitarian elements would be governed by patent law. If this proves to be the case moving forward, then 3D printing users leveraging CC licenses would need a way to determine which elements of a digital design are covered by a license and then be able to communicate this information to others.

The techniques that Field Ready, The Smithsonian and e-NABLE use to mitigate the legal liabilities associated with the risks of sharing digital designs looks different across these three cases. As a small non-profit with limited resources, Field Ready has chosen to limit the sharing of its devices to those that they have been able to thoroughly test and for which they have been able to develop the ideal parameters and specifications. Questions regarding the extent to which their solutions may be violating the IP of another organization or individual have not been explored due to resource limitations. The organization's mission critical work which often involves developing solutions to save lives in high-crisis situations is the first priority. In contrast, The Smithsonian as a U.S. federal government agency has a structured and formalized approach to addressing potential legal liabilities. Like each federal agency, The Smithsonian has a staff of in-house legal professionals led by the General Counsel who are focused on addressing all legal issues related to any of the programs, activities and initiatives of The Smithsonian. This includes the development of clear Terms of Use language that applies to all content made available on a Smithsonian website. The language included is not unexpectedly nuanced in order to accommodate cases in which the Smithsonian may not be aware that someone has IP rights to a particular piece of content that has been shared by the Smithsonian. Rather than stating that the Smithsonian is aware of the IP status of every piece of content that it releases, it instead states that the Smithsonian will release content indicating that it has "no known copyright restrictions" when the Smithsonian is unaware of any copyright restrictions on its use. This does not mean that the Smithsonian knows for sure that there are no copyright restrictions but rather that to its knowledge, there are no limitations. To ensure that The Smithsonian is not liable for the actions of individuals that download or leverage content from the website in ways that may be in violation with the law, the agency also includes language which places additional responsibility on the individual user: "the Smithsonian can offer no guarantee or assurance that all pertinent information is provided or that the information is correct in each circumstance. It is your responsibility to determine what permission(s) you need in order to use the Content and, if necessary, to obtain such permission" (Smithsonian 3D, 2019a).

6.4.2 The importance of co-design in developing solutions that meet the needs of users

In each of the three cases, a co-design approach has been developed and implemented (Hyysalo et al., 2016). The ease with which a digital design can be modified, customized and printed has played a critical role in this process. In the case of e-NABLE a collaborative process is essential to ensuring that a particular upper limb prosthetic meets the needs of a specific patient and that the prosthetic that is ultimately designed fits appropriately so that its fully functional. An e-NABLE team customizing a prosthetic may start with an existing e-NABLE prosthetic design but add certain components or attachments based on the daily needs of an individual, such as an adapter to enable the person to play a musical instrument or more easily take photographs with a camera. For Field Ready, working closely with community members in the city or village where they are helping with the re-building and recovery effort is essential. These individuals have a deep understanding of the cultural context and unique insights into the community that they live in which can help inform the designs of solutions that will be broadly adopted by target users in the community. This co-design process is not only about the creation of the solution, but is also focused on empowering local community members to learn how to use the technology behind 3D modeling and 3D printing so that they can continue to design solutions, repair and maintain 3D printed devices when the Field Ready team is not present. In the case of the Smithsonian, they are actively engaging with different groups of users such as educators, who are testing and providing feedback on several automated tools they are developing that will 1) optimize data processing as physical objects are scanned and digitized in 3D; 2) standardize how content is created so that 3D models can be leveraged across different kinds of technologies (e.g., AR, VR, 3D printing); 3) enable institutions and individuals to engage in more robust storytelling with 3D content.

The individual users working with Field Ready, e-NABLE and The Smithsonian would be considered part of relevant social groups through the social construction of technology. A relevant social group occurs when “All members of a certain social group share the same set of meanings, attached to a specific artifact" (Pinch & Bijker, 1984). Relevant social groups play a critical role in the development of a technological artifact because "Technology development is a process in which multiple groups, each embodying a specific interpretation of an artifact, negotiate over its design, with different social groups seeing and constructing quite different objects" (Klein & Kleinmann, 2002). One of the criticisms around the original conceptualization of SCOT was that it did not take into account the various power structures, relationships and interactions between socially relevant groups and between particular socially relevant groups and other stakeholders which can affect the agency of these groups and the extent to which they are able to play an active role in the shaping of a technology. "Implicitly, SCOT assumes that groups are equal and that all relevant social groups are present in the design process. This fails to adequately attend to power asymmetry between groups. Some groups may be effectively prevented from participating in the design process at all" (Klein & Kleinmann, 2002). In each of the three cases, the organization leverages the Internet and a more relaxed approach to IP which is intentionally designed to encourage others to not only use what has been created, but to modify, hack or build upon the design. This encourages the kind of "interpretive flexibility" that is critical to SCOT. This can be seen in the translation of the fetoscope in the Field Ready case from a 3D printable device to a modified design to be created out of wood using a lathe. In this example, the relevant social group was a group of healthcare providers working in Kenya who believed the fetoscope could be a valuable medical device that could be more widely utilized by doctors, nurses and other healthcare providers who work in low-resource and remote areas of the country if the device could be manufactured locally with readily available materials and technology. In earlier iterations of SCOT, the concepts of closure and stabilization were used to describe how relevant social groups negotiate with a technological artifact using distinctive “technological frames” which guide how a particular group understands a technology, its possible applications and its ability to meet the needs of that group. Closure was said to occur once various relevant social groups resolved contradicting perspectives about the specific technology, prompting the technological artifact to achieve stabilization. Ideas about the role of closure and stabilization have since evolved through the work of additional scholars who recognize that the processes of closure and stabilization are more nuanced and subject to revisions and updates rather than being a process with a final ending. This is due to a number of different factors. Not all relevant social groups have equal access to the technological artifact or access to the technology at the same time, meaning that when a “new” relevant social group has the opportunity to contribute to the development of a technology, this can lead to a de-stabilization of the technology and a re-opening of the technology shaping process. Different relevant social groups can undertake the process of interpretative flexibility simultaneously and these separate processes may or may not converge at a particular point.

In each of these three cases, there are attempts to balance the scripts provided by the designers or the originally intended manner in which the designer of a particular technological artifact conceived the technology would be utilized, with mechanisms which encourage individuals to take an active departure from these scripts to expand upon the functionality of what has already been created. In the case of e-NABLE, examples of how a relevant social group deviates from what was scripted in the original design of a particular prosthetic can be seen in the “remixes” that are documented on Thingiverse. The Phoenix hand is a design which has 31 remixes (Thingiverse.com, 2019a). These remixes range from a modification to the design for a person who only needed three artificial fingers on the prosthetic to the deconstruction of the design for the Phoenix hand into different components to be used as a teaching tool for students learning design engineering (Thingiverse.com, 2019a, 2019c).

6.4.3 Free Innovation can fill a market gap with or without commercialization

At the core of free innovation are the actions of individuals who are motivated to contribute to the development of a technology, solution or device on their own time, without the incentive of monetary payment. Beyond financial reward, there are various reasons why these individuals are driven to work on these projects. This includes a personal need experienced by the individual or someone close to them and the personal satisfaction that comes with contributing to a broader effort that may potentially help a large group of people in need or the significant impact a contribution may have on the life of one person.

For Field Ready, medical devices and tools that might be available in some limited capacity in developing countries of the world such as Nepal and Haiti can become completely unavailable in communities that have been struck by a major crisis. In these situations, traditional manufacturing and supply chains for medical devices or critical equipment parts can fully break down. In their work, the Field Ready team encountered numerous examples of this, ranging from umbilical cord clamps needed to safely deliver babies to braces for stabilizing wrist injuries and connectors to ensure the functionality of breathing ventilators. Existing literature about free innovation discusses how individuals undertake activities that are unpaid, but previous research has not specifically explored examples of free innovation that take place in high stakes situations where the need to develop solutions to problems is extremely urgent and survival may depend on this innovation. This type of free innovation is unique because the process of design, development and iteration around a particular solution or device is accelerated because of the immediate need. Some questions that were not explored here but could provide further insights into this particular variation of free innovation include: Is free innovation in high-crisis situations more conducive to "single free innovators" or "collaborative free innovation"? What happens to free innovations once a high crisis situation has passed and the rebuilding and recovery effort has been more or less completed?

e-NABLE's work with its global network of volunteers that are dedicated to designing, fitting and 3D printing low-cost upper limb prosthetics for individuals who need them sheds light on the ways that free innovation may thrive best when it is not constrained by the norms, policies and structures of a more traditional organization, such as a non-profit 501(3)(c) or a company. The flexibility, modularity and de-centralized configuration of the e-NABLE network make it possible for "collaborative free innovation" projects to form more easily within and across the various e-NABLE chapters. While the majority of e-NABLE's work is carried out by volunteers, the network has developed various mechanisms to recognize the significant contributions of members without financial compensation. This includes the introduction of e-NABLE digital badge awards, "to create more community involvement, reward volunteers and participants and recognize those that do so much to support and expand this growing movement!" (Enabling The Future, 2017). Badges can be earned for activities such as work completed on a specific e-NABLE device, participating in a design challenge and significant contributions to the community more broadly. The use of these mechanisms illustrates the importance of attribution, credit and recognition within a community in the absence of monetary payment. These aspects are not a replacement for money, but rather, they serve as signals to community members that their contributions are important and are actively valued.

In the case of the Smithsonian, in accordance with its mission of “the increase and diffusion of knowledge,” as an institution, it has generally been supportive of “free innovation” activities that users have undertaken using the content and assets shared by the Smithsonian. In specific cases, the Smithsonian has also used its international platform to recognize and encourage particular contributions. Such was the case when Teraoka Gensyou, the Japanese toy designer and artist downloaded the 3D model of a woolly mammoth that Nick’s team had made available through the online repository and turned it into a learning tool and toy with articulated joints. Nick found out about this free innovation on Twitter and asked Gensyou if the Smithsonian could further showcase his work. This resulted in the toy designer authoring a creative post in the form of a comic strip that was published to the Smithsonian blog about his work on the woolly mammoth file (Gensyou, 2018). The Smithsonian also uploaded this modified file of the woolly mammoth with articulated joints to the Smithsonian 3D platform so that other users would have broader access to it. The beginning of Gensyou’s blog post begins, “Exciting things happen when you set data free!” (Gensyou, 2018).

7 CHAPTER 7 Recommendations

The findings from this research indicate that there are a number of different mechanisms that could be developed to address the key issues surrounding the use of Creative Commons by 3D printing users and general challenges around sharing 3D digital design files. These solutions can be divided into three main areas: 1) technical mechanisms; 2) educational initiatives; 3) policy interventions.

7.1 Technical Mechanisms

Members of the 3D printing community that did use Creative Commons and cared about how their files were being used repeatedly described how they felt that the licenses were only minimally useful because in the end, there was no way to easily track how other users were leveraging their files. It is unrealistic to expect that a user who wants to ensure that his/her digital design file is being used in the way he/she originally specified through CC licensing will go online day after day to identify possible infringement. It is important to point out here that this is not only a problem for Creative Commons licensed content but copyrighted content in general. But what is uniquely challenging to 3D printing is that digital files turn into physical objects and there should be a way to ensure that the license and attribution is transferred to the digital object.

It is clear that not all 3D printing users have the need or desire to use Creative Commons. And for those who do use Creative Commons, there is a subset of these individuals who are motivated to use it because they want to ensure that others are able to use what they have created and are not so concerned with whether others follow the guidelines set forth by the license they chose. But for those 3D printing users who use Creative Commons and want to ensure that their creations are being used as specified, a system which tracks the provenance and modification of these digital design files and connects this back to any physical 3D printed version of the object could address some of these critical issues.

There are existing systems which have features similar to what is being proposed here that one could draw from in the design and implementation of such a system. GitHub enables individuals to fork projects- “Creating a “fork” is producing a personal copy of someone else’s project. Forks act as a sort of bridge between the original repository and your personal copy. You can submit Pull Requests to help make other people’s projects better by offering your changes up to the original project. Forking is at the core of social coding at GitHub” (GitHub, 2017). Forking allows both the original project owner in GitHub and other users to see how a project has been modified, creating transparency and an environment conducive to building off each other’s work.

In the art world, provenance, the ability to accurately trace where an artwork originated from and its various owners over the course of its life has been both a challenge and a critical issue. One of the main reasons why provenance is so important is because it is one of the primary ways to verify an artwork’s authenticity. Historically, the process of tracking the provenance of an artwork involved a complex paper trail of personal records subject to error, fraud and forgery. Organizations like the Block Chain Art Collective are leveraging blockchain technology to develop a more secure, digital system that would enable artists and art collectors to follow the journey of these pieces (O’Neill, 2018). The platform developed by Block Chain Art Collective is based on using three components to triangulate the identity/authenticity of a particular artwork: 1) an object, 2) a secure physical identity, and 3) a secure digital identity (“Blockchain

Art Collective," 2019). A block-chain based ledger system creates an unalterable, aggregated, digital record of provenance-related events about a single artwork. When an artwork is sold to a new owner or transferred to an auction house, this is recorded as an entry in the ledger using a string of encrypted numbers identity ("Blockchain Art Collective," 2019). A physical artwork is tied back to a digital record in the system through a tamper-proof seal which is affixed to the artwork. The seal leverages near field communication (NFC) technology to enable authorized individuals to access information about an artwork and make additional entries to the digital record. "The technology behind NFC allows a device, known as a reader, interrogator, or active device, to create a radio frequency current that communicates with another NFC compatible device or a small NFC tag holding the information the reader wants. Passive devices, such as the NFC tag in smart posters, store information and communicate with the reader but do not actively read other devices. Peer-to-peer communication through two active devices is also a possibility with NFC. This allows both devices to send and receive information" ("What is NFC? Near Field Communication Explained," n.d.).

The examples above suggest that there are technical solutions and platforms which include features of a system that would enable creators of 3D digital design files to track and better understand how their designs are being used once they are made available online. Imagine a system where an individual would register a 3D digital design file with information about who created it and the specific Creative Commons license used. In order to download the file, another user would enter information about what they plan to do with the file once they've downloaded it. This information would then be entered into a block-chain based digital record that could be accessed by the original creator and other users. This digital record would provide detailed insights into who downloaded the file, how people are using it and provide attribution to the original creator and subsequent users that modified and built upon this work. In order to ensure that this information could be tied back to any 3D printed objects produced from the file, a digital watermark could be generated through this platform that gets integrated into the digital design file in an inconspicuous area, like the bottom of the object. This digital watermark would be printed out in the form of a series of numbers that a user could then enter into the system to pull up the digital record for the digital design file.

While this system would enable creators of 3D digital files to better monitor how their files are being used, it also relies on self-reporting. It assumes that the users who are downloading the files will be truthful about what they intend to do with the file once it has been downloaded. Individuals who intend to use a file in a manner that is different than what is specified according to Creative Commons probably won't report what they are actually doing. This is especially the case when a user attempts to use a file for commercial purposes that was shared specifically for non-commercial use. To try to identify when a digital design file is being inappropriately used in this context, the system could be designed to be interoperable with the main 3D printing service sites such as Shapeways, Materialise and Sculpteo. These 3D printing service sites are where individuals can purchase 3D printed objects based on designs uploaded by various designers. A plug-in could enable a creator to scan the digital files on the Shapeways marketplace for example to identify whether there are any files that closely resemble that design. This would require the buy-in and collaboration among these 3D printing service providers however.

7.2 **Educational Initiatives**

In order for 3D printing users to be able to make more informed decisions about how they would like to share their work if at all, a wider scale educational effort should be undertaken to provide members of the 3D printing community with easy-to-use resources around intellectual property. A freely available online guide or series of short videos clearly describing the following information could help to fill the informational gaps and clarify misunderstandings about different options for sharing and distributing content and their implications for who has access to the content and what they can do with it:

- How patents, copyrights and trademarks relate to 3D printing, specifically around digital design files
- How copyright and Creative Commons licenses work together and what they actually protect
- The organizations and resources that 3D printing users can leverage for support and questions around 3D printing and IP issues moving forward

An online guide containing the information above that was developed in collaboration with several key organizations and institutions would signal to the 3D printing community that this is a trusted resource and would increase the chances that such a guide would be utilized. These organizations include the U.S. Copyright Office, U.S. Patent and Trademark Office, Creative Commons, Thingiverse, Shapeways and Public Knowledge. The U.S. Copyright Office administers the national copyright system and provides advice on copyright law to Congress, federal agencies, the courts and the public while the U.S. Patent and Trademark Office is the agency responsible for granting U.S. patents and registering trademarks (USA.GOV, 2019).

Thingiverse is the largest online repository of freely available digital designs for 3D printing and Shapeways is the world's largest 3D printing service. Public Knowledge is a non-profit advocacy organization that has consistently advocated for the rights of 3D printing users and the importance of keeping 3D printing an open and modifiable technology (Weinberg, 2010). Creative Commons currently offers an in-depth online course focused on CC licenses, open practices and the ethos of the Commons, but this course requires a significant time commitment of 10-weeks, has a cost of $500 and is not specifically tailored to the issues associated with 3D printing. Thus, a more condensed, freely available 3D printing user-friendly guide could be beneficial to the community.

This research discovered that different fields have differing levels of IP concerns around 3D printing. Those engaged in the design of 3D models for use in education are generally less concerned with the possibility of violating an existing copyright and more focused on sharing their digital design files if they believe it would be helpful to other educators. In contrast, individuals creating digital designs of medical devices and spare parts have more concerns about how what they have created could be in violation of existing IP laws. To further understand how IP concerns related to 3D printing differ across fields, sector-specific working groups could be created and convened to unpack these issues in greater detail. This would also provide these 3D printing users with an opportunity to connect with other individuals within their field who are also facing the same questions and issues, creating a space to address these challenges together.

7.3 Policy Interventions

The Digital Millennium Copyright Act of 1998 (DMCA) was designed to implement two 1996 treaties from the World Intellectual Property Organization which made it a criminal act to develop and distribute technologies or services that would circumvent technical protection measures (TPM) aimed at limiting access to copyrighted works. In order to address technological developments that might fall under the DMCA but should be considered as a potential exception in order to preserve technological innovation, Section 1201 of the DMCA, "Exemptions to Prohibition Against Circumvention of Technological Measures Protecting Copyrighted Works," "provides the Librarian of Congress, upon the recommendation of the Register of Copyrights following a rulemaking proceeding to determine whether the prohibition on circumvention is having, or is likely to have an adverse effect on users' ability to make non-infringing uses of particular classes of copyrighted works" (Digital Millennium Copyright Act, 1998). Every three years the Librarian of Congress engages in a rulemaking process which enables organizations, institutions and individuals to submit requests for exemptions to the DMCA. Each exemption request is reviewed, with opportunities for the public to provide input online and through in person hearings and workshops. The Librarian of Congress ultimately makes the decision regarding each exemption request based on the recommendation from the Register of Copyrights who receives input from the National Telecommunications and Information Administration (NTIA) in combination with the public input. Over the years, this process has led to exemptions that include: enabling consumers to unlock their cell phones to make software modifications that make it possible for mobile phones to use applications from sources other than the phone maker, allowing individuals to leverage short clips of copyrighted video content for the purposes of remixing to create noncommercial works for criticism or comment and making it legal for people to access computer programs that control cars and farming vehicles for repair (Digital Millennium Copyright Act, 1998). A DMCA-like exemption which makes it possible for individuals to leverage designs of medical devices and spare parts such as washers and screws for non-commercial use would ensure that individuals could create and distribute these tools for humanitarian purposes without fear of legal prosecution. However, such an exemption would most likely need to be developed in accordance with patent law.

At the national level, one can look to previous initiatives developed and implemented by previous presidential administrations aimed at supporting and encouraging the sharing of data, the crowdsourcing of ideas and solutions and open innovation to understand how the federal government could more formally facilitate and encourage the sharing and innovation activities of the 3D printing community. The Obama Administration developed formal initiatives focused on open data (Data.gov), open innovation and crowdsourcing (Challenge.gov), the Maker Movement (Nation of Makers initiative) and citizen science (CitizenScience.gov), which aligned with President Obama's priorities around providing the public with the data, resources and technology to solve pressing global and local problems, foster entrepreneurship and economic development in communities around the country and create new educational opportunities for students in the fields of science, technology, engineering and math (STEM). These formal initiatives translated into specific actions taken by federal agencies and the President:

- "In May 2013, President Obama issued an Executive Order and policy guidance on making open and machine readable data the new default for government information. To date, more than 180,000 Federal datasets and collections have been made available on Data.gov" (Obama White House, 2016).
- "Since 2010, more than 80 Federal agencies have engaged 250,000 Americans through more than 700 challenges on Challenge.gov to address tough problems ranging from

fighting Ebola, to decreasing the cost of solar energy, to blocking illegal robocalls. These competitions have made more than $220 million available to entrepreneurs and innovators and have led to the formation of over 275 startup companies with over $70 million in follow-on funding, creating over 1,000 new jobs" (Obama White House, 2016).

- "The Administration has expanded opportunities, including those efforts listed on CitizenScience.gov, for research agencies to work with citizen scientists and use crowdsourcing approaches. Researchers have estimated that the in-kind contributions of more than a million citizen-science volunteers to biodiversity research alone have had an economic value of up to $2.5 billion per year" (Obama White House, 2016).

As an extension of these related initiatives, future policy efforts could continue to encourage the creation and sharing of 3D digital designs and elevate the importance of resolving unanswered questions around how copyright and patent law apply to 3D designs and the objects that are created from them. These actions could take the shape of federal agencies such as the National Science Foundation, Institute for Museum and Library Services and the Smithsonian providing funding for research and the development of resources that continue to facilitate the development and distribution of 3D content. A federal agency or multiple federal agencies could launch a challenge-based competition to accelerate the development of 3D printing technology with the caveat that all entries are open source to ensure that anyone has the ability to leverage these innovations. Similarly, an agency could create an open competition focused on a 3D-printable, low-cost solution to a problem or issue where entries are open source or use Creative Commons licenses.

At the local, regional, state or national level, events or convenings could be organized to showcase and celebrate the connections between a more open approach to sharing 3D content and tangible benefits to a community, including the ability to solve community-based problems and have a positive impact on economic development. Such efforts create opportunities for more individuals and relevant social groups to actively participate in these activities, but also engage in the dialogue and debate related to the important questions surrounding 3D printing and IP.

Focusing on policy interventions that can be implemented at the regional, state or local level is equally important. Such approaches could be developed and supported through the help of networked organizations of policymakers such as the U.S. Conference of Mayors, the National Governors Association or the National League of Cities.

Working closely with educational institutions, in particular post-secondary institutions such as community colleges and four-year universities to develop a course or program requiring all incoming students to learn about intellectual property and the different choices they can make about what they do with their IP could be an effective mechanism for reaching a large and critical group of current and future innovators and problem-solvers. Currently, higher education students may be required to learn about plagiarism, which is only one aspect of understanding intellectual property. Historically, students in majors that directly involved creating an object or device that could be patented such as engineering or product design might learn more about intellectual property, but given the availability of tools, technologies and resources which enable many more individuals to create content, knowledge and solutions, it is critical for everyone to have a deeper understanding of the choices that he/she can make about how to share or not share what has been created.

8 CHAPTER 8 Contributions, Future Work & Conclusion

As previously described the main theoretical concepts of the social construction of technology, recursive publics and free innovation are used individually and in conjunction with one another to describe, unpack and further understand the ways that 3D printing users go about sharing the digital designs that they create, the role of IP in these activities and other critical factors in this process. This research not only uses these theoretical concepts as interpretive lenses, but makes unique contributions to the existing body of knowledge around SCOT, recursive publics and free innovation.

With regards to SCOT, I observe that the lines between customization and interpretive flexibility which lead to substantive changes in the functionality of a technological artifact can be blurred. Sometimes the act of customization, such as the modifications made to the 3D printable fetoscope to create a version that could be created out of wood, while seemingly minimal, can lead to significant changes, such as making it possible for an entirely new group or population to be able to use a technological artifact. This example suggests that it may be possible for substantial acts of customization to lead to real changes in the functionality of an artifact even if significant differences in interpretive flexibility are not recognized. Part of this is dependent on how "functionality" is defined.

Through the case of e-NABLE, I describe how a community underwent a process of transforming into a more traditional organization in order to align with the requirements and pressures of power structures, hierarchies and existing legal policies and the questions, challenges and realizations, which led them to evolve into what has eventually become a recursive public. This case describes in detail the ways in which the development of a recursive public can be indirect and circuitous and subject to the tensions, processes and norms of traditional institutions and infrastructures.

While free innovation activities are juxtaposed with producer innovation, several different examples described through this research identify a type of hybrid innovation activity in which an individual can simultaneously participate in producer innovation and free innovation at the same time, a practice which has not been covered widely in previous efforts to understand free innovation behaviors. This suggests that being a free innovator and engaging in producer innovation can occur on a spectrum and that these activities are more fluid than have been formerly described.

Collectively, this research suggests that while IP issues do create barriers to 3D printing users sharing the digital design files that they have created, many 3D printing users have found different ways to address these issues. They may make the decision to share what they have created in some format anyways, despite the uncertainties of violating an existing patent or copyright. Through the interviews and case study analyses we discovered that beyond IP issues, there are also a variety of other factors that can affect what 3D printing users share. These factors include concerns about whether a particular design will be useful to the broader community, possible safety issues if a design is not printed using the specifications provided and bandwidth limitations that make it difficult for users to share their designs even when they intend to do so. This research found that 3D printing users do use Creative Commons, but not to the extent that I had originally anticipated. When 3D printing users do use Creative Commons, users appear to have only a partial understanding of how the licenses function and what they protect.

Through the interviews conducted as part of this research, I have a deeper understanding of the role that users are playing in the design and development of 3D printed innovations, the tools that facilitate 3D design and digitization of objects and the advancement of 3D printing hardware. This work contributes to the body of research around the social construction of technology by further describing how the roles between user and producer are porous and the ways that individuals can play more than one role at any given time. Findings also shed light on the specific strategies and techniques that producers employ to engage with users and develop long term, meaningful relationships with them in order to foster a sustainable ongoing co-design process around a specific technological artifact, whether that be a digital design file or the next iteration of a 3D printer.

The examples of free innovation covered in this study describe how critical it is for these projects to exist, despite the risks that may be present. As discussed by Von Hippel, free innovation projects often address an unmet need that the market may never focus on because for companies, this would not be a profitable endeavor. At the same time, individuals who work on a free innovation project also create tensions when they innovate upon an existing product in a manner that may make it more widely accessible and more affordable, which companies may interpret as undercutting their business. This tension is necessary in order to incentivize existing players in a sector or industry to consider different approaches to technological development.

I found that the formation and maintenance of a recursive public is one way in which free innovation projects and initiatives are able to sustain themselves. In other words, the creation of what Kelty describes as a public "concerned with the ability to build, control, modify and maintain the infrastructure that allows them to come into being in the first place and which, in turn, constitutes their everyday practical commitments and the identities of the participants as creative and autonomous individuals" creates the conditions for free innovation to not only survive, but to thrive. This approach is particularly important if producers do not adopt an innovation for wider distribution or the approach that producers take to turn an innovation into a product is not aligned with the original overall goals of the project.

As with any research project, there are specific limitations to the approach taken here. This research focused on the collection and analyses of qualitative data, from a somewhat smaller sample size of 20 open-ended interviews. While this primary research was expanded upon through secondary research, subsequent research could include larger samples of interviewees. My existing sample of interviewees spanned across twelve different fields. While this was intentional, an evolution of this research could focus on deepening the understanding of the differences in approaches to IP and 3D printing between users in specific fields. This would require conducting interviews with a greater number of individuals working in one particular field. For example, it could be valuable to examine these phenomena between two distinctive fields that directly inform one another, such as unmanned aerial vehicles and environmental conservation. Drones are increasingly being utilized for the purposes of environmental monitoring and conservation.

In addition, future work could include the use of quantitative data to confirm or dispute some of the initial findings laid out here. In particular, the interviewees who took a more open approach to sharing their digital design files did not have any significant experiences filing for copyrights or being patent holders. Leveraging publicly available data sets released by the U.S. Patent and Trademark Office regarding patents and their patent holders and cross referencing these with data about Creative Commons users could shed light on the extent to which an individual's approach to managing his/her IP exists on a changing spectrum rather than skewing towards a more open or more closed approach.

As 3D printing continues to evolve and more individuals gain the skills and experience to 3D model and scan objects to create digital designs, questions about intellectual property will continue to be critical to understanding how IP might enable or constrain the development of this technology and future technologies. Findings from this research suggest that the community of 3D printing users is challenging the traditional legal boundaries of IP in order to use the technology in ways that meet their needs, the needs of others and address critical problems in various fields. The technical mechanisms, educational initiatives and policy interventions discussed provide a few places where we can start to resolve some of the issues and uncertainties related to 3D printing and intellectual property that could be detrimental to the advancement and the use of the technology moving forward.

9 Appendices

9.1 Appendix 1: Overview of 3D Printing

Although 3D printing was developed in the 1980s, up until several years ago, the technology was used primarily for a limited range of industrial applications. Engineers, designers and architects leveraged 3D printing for rapid prototyping, creating structure models and producing complex, specialized one-off parts. In its early years and even up until the early 2000s, an individual needed a significant amount of training and knowledge to use the technology, including how to use CAD to digitally model objects. These industrial 3D printers were also extremely expensive models ranged in price from thousands to hundreds of thousands of dollars.

3D printing is a term used to encompass several different additive manufacturing techniques. Additive manufacturing is a process in which three dimensional objects are built layer upon layer using different materials, including plastics, metal, food and today, even human tissue. Additive manufacturing differs from traditional methods of manufacturing which involve starting with a larger amount of material than required and cutting away from the material to make the objects. In order to 3D print an object, a 3D digital design file must first be created using 3D modeling software. In the 1980s and 1990s, computer-aided design (CAD) software was used to create these models and required a certain level of training and expertise. In the last 5-7 years, more user-friendly 3D modeling software has been introduced that can be used by individuals without a technical or design background, including Tinkercad, SketchUp and Morphi. When a 3D model is ready for printing, it is typically saved as an STL file, which is the industry standard file format for 3D printing. The STL file uses a series for triangles to represent the surfaces of the model. Once the STL file is created, the model is converted into G-Code, machine readable language that the 3D printer recognizes through a process of “slicing.” This process can be undertaken using an open source software like Slic3r or Cura that is available online. Some 3D printers come with software that also has these capabilities.

There are different technical approaches to 3D printing, which can be distinguished by the way in which layers of material are created and built, types of materials and print quality. This includes Stereolithography (SLA), Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), Material Jetting (MJ) and Electron Beam Melting (EBM) (All3DP 2019).

For the purposes of this discussion, we will focus on two widely used methods: 1) Stereolithography (SLA); 2) Fused Deposition Modeling (FDM). Stereolithography is the first 3D printing process to be patent protected in 1986. With SLA, the build process begins with a pool of resin. A laser beam is aimed at the pool of resin, tracing the cross-section pattern of the 3D object one layer at a time, simultaneously curing the layer before tracing the next layer (Additive Manufacturing, 2013).

Fused Deposition Modeling uses thermoplastic filament which is threaded through an extruder with a heating element. The heat melts the plastic at a specific temperature and as it passes through the extruder, gradually builds the 3D object layer by layer, again in a cross section pattern (Additive Manufacturing, 2013). The plastic cools and hardens by itself, so no additional laser technology is required for curing. FDM is the process used by the majority of consumer-oriented printers currently available, including RepRaps, MakerBots, Ultimakers and Lulzbots.

When key patents for Fused Deposition Modeling expired in the early 2000s, this prompted the creation of open source 3D printing initiatives such as RepRap and Fab@Home, which sought to democratize the technology and make it accessible to a wider audience. It was these open source projects which laid the groundwork for commercial 3D printing start-ups to sell 3D printer kits and fully assembled 3D printers to the general public. From the very beginning, the build instructions and plans for the plastic parts of the RepRap were made publicly available on the project wiki (reprap.org/wiki/) via the GNU general public license (Bowyer, 2009). Making this information freely available served as a catalyst for the peer-to-peer sharing of information about everything from how to improve the functionality, features and print quality of the earliest machines to troubleshooting printing issues with specific objects. The significance of RepRap and more generally the open source movement in 3D printing can be observed by tracing the numerous consumer-oriented 3D printers that are on the market which are derivations of RepRap or contain a substantial number of the same features and functionality.

In the last 5-7 years, the market for consumer 3D printers has experienced a number of significant developments. Companies that held a significant amount of market share have folded or sold their businesses to larger companies, such as MakerBot, which was acquired by industrial 3D printing company Stratasys in 2013 for $604 million (Clay 2013). Today U.S. and European 3D printing companies are finding the consumer 3D printing market saturated, faced with increasing competition by international companies, primarily from China, which are producing similar models but three quarters or half the price.

Today applications for 3D printing span across a broad range of fields from the aerospace, auto, fashion and food industries to biomedicine and marine biology. This technology will continue to revolutionize how people can design and make things because 3D printing[4]:

1) **Can be used to easily and cheaply customize products**, from hearing aids and glasses to shoes and jewelry;
2) **Is a cost-efficient way to rapidly prototype ideas**, increasing the speed with which individuals can bring products and solutions to market;
3) **Has the capabilities to produce highly complex, intricate and geometric object designs** from musical instruments and fabrics to rocket injectors and artificial ears;
4) **Is one of several technologies enabling "desktop manufacturing"-** making it easier for entrepreneurs to design and produce products locally; and
5) **Is lowering the cost of previously expensive devices**, such as prosthetics and medical implants

Access to 3D printing continues to grow in communities around the country, where students and adults are now able to access 3D printers in local libraries, schools, universities and maker spaces- shared physical spaces where individuals use tools and technologies to build things. There are also 3D printing services like Shapeways or Materialise available where users can upload their digital designs online and their 3D printed objects will be mailed directly to them. For individuals who do not how-to 3D model, online sites such as Thingiverse.com contain digital designs of objects which people can freely download and use. Thingiverse, for example, contains over 1.4 million object designs.

[4] Basiliere, P., Burton, J., Kutnick, D., Shaffer, V., & Shanler, M. (2016). Predicts 2017: 3D Printing Accelerates. *12*(01), 2016. https://www.gartner.com/doc/3514717

9.2 Appendix 2: Applications

There are a number of fields where applications of 3D printing are leading to innovative solutions to pressing problems, advancing scientific discovery and contributing to the development of a robust advance manufacturing industry in the U.S. Below is a selection of fields where 3D printing is being leveraged to expand technical capabilities and facilitate scientific discovery.

9.2.1 Bioengineering/Healthcare

In bioengineering and healthcare, scientists and physicians are using 3D modeling and printing for cutting edge research. A surgeon is now able to use a 3D printed model to study her patient's heart and plan the surgical procedure. In 2014, the National Institutes of Health launched 3D Print Exchange, a website of freely available 3D-printable scientific models that include viruses, anatomical parts and lab equipment that anyone can download and use for medical learning, scientific discovery and education.[5]

Significant breakthroughs are being made in bioprinting, which uses human biological materials like cells and tissue. Michael Alpine from Princeton University has developed a technique using 3D printing which produces working ears from real cartilage cells, silicone and nanoparticles as well as an approach to repairing damaged nerves through 3D printing.[6] Larry Bonassar's research group at Cornell University is developing new approaches to 3D printing to regenerate

[5] 3D Print Exchange. https://3dprint.nih.gov/

[6] B. N. Johnson, M. C. McAlpine. "From Print to Patient: 3D Printing Personalized Nerve Regeneration." The Biochemist 38, 28-31 (2016). http://www.biochemist.org/bio/03804/0028/038040028.pdf

bone and cartilage found in various parts of the human body.[7] Organovo, a biomedical company, has started commercially selling 3D printed human liver tissue that can be used to conduct medical drug impact studies over longer durations than the current industry standard.[8]

3D printing is also significantly advancing the field of medical implants. In 2012, an 83 year old woman became the first person to receive a 3D printed titanium jaw implant after suffering from a bone infection.[9] Glen Green, a pediatric head and neck specialist, successfully developed a customized 3D printed "splint" enabling a baby previously suffering from a defective windpipe to be able to breathe on his own.[10]

Finally, 3D printing is making it easier and more accessible for individuals around the world to gain access to low cost medical devices, including prosthetics. A 3D printed prosthetic hand can now be made for around $50 in materials. In Kansas City, 17-year old Mason Wilde modified an existing design for a prosthetic hand for his 9-year old friend and 3D printed it at his local library.[11] The increasing presence of low-cost 3D printers in publicly available locations such as libraries, museums and schools is making it possible for individuals to develop their own customized solutions locally.

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[7] Alyssa J. Reiffel, Concepcion Kafka, Karina A. Hernandez, Samantha Popa, Justin L. Perez, Sherry Zhou, Satadru Pramanik, Bryan N. Brown, Won Seuk Ryu, Lawrence J. Bonassar, Jason A. Spector. High-Fidelity Tissue Engineering of Patient-Specific Auricles for Reconstruction of Pediatric Microtia and Other Auricular Deformities. (2013). http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0056506

[8] Organovo's ExVive™ 3D Bioprinted Human Liver Tissue Models. (2016) http://organovo.com/tissues-services/exvive3d-human-tissue-models-services-research/exvive3d-liver-tissue-performance/

[9] Transplant jaw made by 3D printer claimed as first (2012). http://www.bbc.com/news/technology-16907104

[10] Robert J. Morrison, Scott J. Hollister, Matthew F. Niedner, Maryam Ghadimi Mahani, Albert H. Park, Deepak K. Mehta, Richard G. Ohye, Glenn E. Green. Mitigation of tracheobronchomalacia with 3D-printed personalized medical devices in pediatric patients (2015). http://stm.sciencemag.org/content/7/285/285ra64

[11] Kansas teen uses 3-D printer to make hand for boy. (2014) http://www.kansascity.com/news/local/article337980/Kansas-teen-uses-3-D-printer-to-make-hand-for-boy.html

9.2.2 Aerospace

Industry leaders such as GE and SpaceX are using cutting edge techniques in 3D printing to create next generation engines for their aircraft and spacecraft. For example, GE is using a new method of 3D printing to produce light-weight titanium blades for its jet engine turbines. Using this new method has enabled GE to reduce the weight of the turbines while achieving production efficiencies significantly.[12] Recognizing the potential for innovation, GE has been investing in the creation of additive manufacturing facilities, including a $500 million hub in Auburn focused on jet propulsion and a $32 million facility outside of Pittsburgh, in collaboration with America Makes.[13] In 2016, GE tested the world's largest jet engine ever built, which included 3D printed fuel nozzles, "which replaced conventional nozzles that had more than a dozen welded parts. This helped reduce weight by 25%, increase fuel efficiency, and make it the company's quietest engine to date."[14]

NASA is also exploring the possibilities of 3D printing in space. In December 2014, the world's first zero-gravity 3D printer was installed on the Space Station and has already printed a wide variety of objects to assist the astronauts, the first of which was a wrench.[15] More recently, researchers at NASA's Jet Propulsion Laboratory have developed prototypes of 3D printed

[12] GE reveals breakthrough in 3D printing super light-weight metal blades for jet engine.(2014) http://www.3ders.org/articles/20140818-ge-reveals-breakthrough-in-3d-printing-super-light-weight-metal-blades-for-jet-engine.html
[13] GE celebrates grand opening of first additive manufacturing center in Pittsburgh. (2016) https://www.americamakes.us/news-events/industry-news/item/874-ge-celebrates-grand-opening-of-first-additive-manufacturing-center-in-pittsburgh
[14] GE started testing the world's largest jet engine. (2016) http://www.gereports.com/video-ge-started-testing-the-worlds-largest-jet-engine/
[15] Space Station 3-D Printer Builds Ratchet Wrench To Complete First Phase Of Operations. (2014) https://www.nasa.gov/mission_pages/station/research/news/3Dratchet_wrench

flexible, woven metal fabric akin to chainmail, which could be used to protect astronauts or cover large antennas.[16] This "space fabric" provides "reflectivity, passive heat management, foldability, and tensile strength."[17]

9.2.3 Hardware and Electronics

Making it possible to 3D print objects which include functional elements such as sensors or switches and other electronic or mechanical components could change the way we hardware and electronic devices are designed and produced. Scientists have succeeded in using 3D printing to print lithium-ion and graphene batteries to power small transmitters or sensors. Voxel8, a desktop 3D printer can print smaller electronics like quadcopters, electromechanical parts and circuit boards.[18]

9.2.4 Spare Parts

Individuals are using 3D modeling software to design spare parts for everything from automobiles to household appliances. Designs for spare parts can also be found online through Thingiverse or Kazzata, an online marketplace for 3D printable spare parts. The U.S. Army's Rapid Equipping Force has deployed mobile prototyping labs, which include 3D printers to the front line in places like Afghanistan. Placing 3D printers close to the frontlines can minimize the amount of spare parts that soldiers are required to take with them while enabling them to innovate solutions to technical problems as the rise in the field. The Navy's "Print the Fleet"

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[16] NASA research into 3D printed space fabrics for off world missions. (2017) https://3dprintingindustry.com/news/nasa-research-3d-printed-space-fabrics-off-world-missions-111163/

[17] 3D Printed Space-Age "Chain Mail" Is in Development at NASA. (2017) https://futurism.com/3d-printed-space-age-chain-mail-is-in-development-at-nasa/

[18] Voxel8. http://www.voxel8.com/

program aims to engage sailors in using 3D printing and developing procedures, policies and an infrastructure for printing spare parts.[19]

[19] Makers in the Military. (2016) https://obamawhitehouse.archives.gov/blog/2015/12/10/makers-military

9.3 Appendix 3: Interview Guide for Participants

1) *Tell me about your experience with 3D printing.*
Follow up questions:

- How did you get started?
- What do you use 3D printing for?
- Do you 3D model your own creations and if so, what software do you use for this purpose?
- Do you use 3D models that other people have created?

2) *Once you've digitally designed an object, what do you typically do with the file?*

Goal of Question:
- Understanding where the digital file gets stored / distributed / shared

3) *How do you decide whether or not to share the digital design file for something you've created?*

Goal of Question:
- Understanding the decision-making process around sharing digital design files. How they weigh the advantages and disadvantages.

4) *When you want to share a design file, how do you do this?*

Goal of Question:
- Insights into the technical process and functional steps required to actually physically share the file.

5) *What has been your experience, if any, in using Creative Commons for sharing or using work created by others?*

Follow up questions

- Have you used Creative Commons (CC) licenses for your digital design files?
- Which CC licenses do you use and why?
- Have you used digital design files created by others that use CC licenses?
- Have you used CC licenses for other types of content you've created?

6) *What technical and non-technical challenges have you faced in sharing design files for the things that you've created?*

7) *What concerns, if any do you have when it comes to sharing your design files with others?*

8) *Have you ever created anything that is protected with traditional intellectual property, such as copyright or patent or that you'd consider protecting with this type of IP?*

9) *What are your thoughts on open source?*

10) *Is there any related topic we have not discussed you would like to raise?*

11) *Could you share two individuals that you know who are also 3D printing users and might be willing to speak with me about this research?*

9.4 Appendix 4: Excerpts from Interviews Conducted

9.4.1 Jane (Interviewed 9/30/18)

Advantage with 3D printing is that you can make any one of a thousand things- there are restrictions on design and materials but event people who could 3D model, they could still get the 3D printer to work, so they could create a factory of 15 basic and critical medical items.

Concerns around 3D printing when it comes to the aid work:

- Is the 3D printer someone is using of the right quality?
- Can it really make medical equipment?
- Is it clean?
- What are the parameters for which you can have guidelines so that people know it's safe?

Haven't pushed things for sharing because of concerns around safety.

Goal for Field Ready is not the tech. It's using local resources, local people, materials, resources so that they can replicate what Field Ready does even after they're gone. So they only bring 3d printers where it makes sense.

Jane uses Creative Commons- she feels like they're used more for artistic stuff, doesn't apply for medical tools. One of their concerns was around designing something that might be patent protected.

Jane prefers open source because people can hack it and make it better, but then you have to track this.

9.4.2 Elena (Interviewed 11/2/18)

Samantha grew up in Detroit and her first job was at a steel mill. 3D printing made sense to them as a tool that could help people in local communities to be able to make something that they could actually use, but it would need to be bigger than a desktop system. They were looking for something that would be large enough to print a composting toilet- that was the initial concept.

Elena was a social entrepreneur in residence at NASA and found that $10K was a key price point for purchasing. Concept of open innovation was standing up. The team was a finalist in a competition that Jack Daniels hosted with Instructables and that they gave them a little confidence and they started to get a following online just by sharing the idea. 2012 EWB then was called EWB Black Ops, then they formed a club that was meeting to explore the idea of creating a printer in more detail.

This became more of a solid idea when in 2012, Brazilian govt gave the team $40K to create the first prototype and scale. Elena moved to Santiago in 2013. Ended up being able to get a working prototype finished in 8 weeks in time for SXSW and was able to exhibit it at a booth there. They also launched the Kickstarter at the same time and TechCrunch article was published after an editor there saw it at the conference, saying "3D printing is now bigger than a bread box" and they were funded in 27 hours ($250K).

9.4.3 Ben (Interviewed 9/19/18)

In 2011 he received a teaching fellowship to go to Rwanda to study effects of STEM education on the country and how it was being used to create Rwanda as a hub for STEM. He contacted D-Lab at MIT and looked for ways to scale down the humanitarian engineering work they were doing that would be suitable for younger students. D-Lab gets MIT's students to work on real world international dev problems.

Connected kids around the world using STEM to apply their learning and connect with one another. Efficient biomass project- kids from Brazil, US, Rwanda. Rich was working at the intersection of design, engineering and STEM.

In 2013, saw a video about the first 3d printable prosthetic- Ivan Owen and Richard Van Ness created the 3D printable prosthetic and posted the design online. "In those ten seconds when I realized what the video was about, my life completely changed."

His son Max had been born without fingers on his right hand and the kid that they were designing for had the same condition as Max. He realized that he had no idea what 3D printing was, but realized that this would make a great real life, innovative approach to engaging students in STEM through real-life problems. Rich wanted to build one of these prosthetics for Max (who was 3 at the time), so that he could learn more about 3D printing. As he was chatting with Richard, he thought it would make an amazing project for his 8th grade science students. Got 12 kids to work as a club with Rich over the course of a year. After meeting every day for 45 minutes over the course of 6 months, they had created a device for Max. They didn't have a 3D printer to start, but had heard a high school half an hour away and asked if they wouldn't mind printing off the parts. Students at the high school were the ones running the 3D printer. Students printed the pieces for the device. Max was able to pick up things with the hand that he would never have been able to do.

9.4.4 Gus (Interviewed 10/5/18)

As tech increasingly becomes an important part of education, the trend is that there is increasingly a demand for assistive technologies for students who are visually impaired, which means there are more districts who are hiring people like Gus.

Gus tries to keep up with things in this field with visually impaired students- four years back, heard about 3D printing and how it could be useful. He and a colleague wanted to see what they could do with it- they approached their department to see if they would purchase a 3D printer. They didn't have any experience with 3D printing. Had no idea what they were doing, but once they got approval, they knew they would have to prove its worth to the department. They approved it but then they also wanted to see what they did with it.

Gus progressed into actively designing things because of a visually impaired teacher (TVI)- one in particular was very tech heavy and forward thinking, was always making things to fill needs.

Often Gus and this teacher would use cardboard and such. Usually you're handed an assignment and make it tactile in order to help a student gain access to the curriculum. She asked him if he could use the 3D printer to create smaller things for a student to make his learning more tactile. For Gus's job, he is so used to having to problem solve and figure out solutions to challenges so it was natural for him to teach himself 3D modeling. In general, he's always known that he needs to figure it out. He didn't have anyone show him any part of the project. TinkerCAD was what Gus first learned on.

He doesn't fully understand Creative Commons licensing. Gus normally includes detailed instructions and how to use something he designs- he tries to include a video. "I don't think I fully understand the licensing on it. To be honest, I don't think I fully understand the different licenses on Thingiverse." Gus's perspective on keeping things open source because in his field, it's so small and small and spread out that he feels like they're on little islands fighting the same fight for accessibility.

9.4.5 Cara (Interviewed 11/3/18)

Interested in ways that 3D printing allows them to replicate some of the archives that are otherwise not currently accessible unless you go to the couple of spots around the country where they are physically located. These are rare books with preservation issues, so you have to be careful how you handle these things and you can't interact with them the way you would in the 19th century. "The current digital world as it's constructed limited our access to archives even if we have the fantasy that everyone can have access to everything. It's not really true when all the tools are based on visual media."

Solutions that people have produced so far have to do with translation rather than reproduction. The technology translates materials for low vision and blind individuals rather than reproducing for these individuals. Ex. if you wanted to read tactily raised print book that was printed in the 19th century of the Scarlet Letter, it doesn't do much for you to here an audiobook of the story- doesn't provide the actually experience of using this kind of resource.

Touchthispage.com - this will be the online site of for the exhibit where people can download and print the objects. We'd like for this to be accessible for communities that have been left out of digital innovation. They want the website to be community oriented. Launch the website at the same time as the exhibits in January.

On IP- she hasn't talked about it much because they're just piloting something with 6 objects. She doesn't see why it needs to be proprietary- the goal is supposed to be to make it accessible. It's really about getting the archives out there for people. They are creating original content in a certain sense but it's meant to be used by people so she doesn't understand why they need to protect this work. She's an English professor and her other colleague is a librarian so they're not looking to create a business out of this. There are probably elements of it that could be monetized, but she doesn't care about that.

"Even from a less altruistic side, in terms of our careers, the value in this is not in monetizing it, the value is in doing it. We're not incentivized to make money out of it, but the real value for us as scholar is to be able to write about it. This is the amazing thing about academia- you get paid to have ideas and share them with the public."

9.4.6 Violet (Interviewed 11/5/18)

Don't box in what the repository is because you don't know what your user is going to want. In the case of 3D print exchange, they were very focused on 3D printing and framed the platform this way when in actuality users might have an interest in using the digital files for VR or AR or no printing at all. You'll have info and metadata that is specific to 3D printing but at the end of the day you have digital assets that can be used across a broad variety of applications. Refocus on just 3D digital assets.

How difficult is it to port a current digital asset of 3D print exchange into a VR environment? This is still to be determined. Meghan is trying to figure out how to get workflows to help with this. The way that it works now is that you upload an STL and then generate an X3D file that's used to be displayed in the browser. So they have the capability to generate these other files. The question is whether they should use a 3MF or OBJ. Are people using it or not using OBJ? She doesn't know.

If you post something on Thingiverse, a creator makes this available under the assumption that the file will be downloaded and printed. So if there's a chance that this digital asset would be used for something else, does the creator need to use a different kind of license beyond Creative commons? Should the file be able to be used in a video game? This is an issue particularly for platforms like Thingiverse or GrabCAD. These platforms need to consider how they think about the files that get uploaded. What if it gets used in the virtual world?

9.4.7 Nan (Interviewed 12/19/18)

When it comes to IP, the makerspace is not subject to the traditional tech transfer requirements of the university. The space is not funded by research dollars, so the things that are developed and created in the space are retained by their inventors in terms of IP ownership. For example, there are student startups in the space that are using the space to develop their prototypes. This is an ongoing debate about how to create makerspaces on the grounds of colleges and universities that encourages open innovation, invention and entrepreneurship.

This project involves masters students, PhDs and post-docs. Some master and PhD students have some background in 3D modeling, others may not, so it differs. Master students are diverse- law, MBAs, health tech- they may never have engaged in making or 3D modeling/printing. The makerspace has used seminars through different companies to get them on-boarded. Some "super makers" host open hours where students can ask questions. These open hours focus on people's pain points and then they come in with 3D modeling questions.

She encourages students to learn a tool for a real project at hand. She personally wouldn't sit down herself to 3D model or help someone else with a technical issue they have with the technology, but she'd develop an infrastructure and process for students to go from idea/solution to how they can actual get to the 3D model itself. She also has students use open source platforms online that have downloadable models that you can then modify or add to. Lots of peer mentoring involved.

9.4.8 Ted (Interviewed 12/5/18)

Examples of interesting 3D printed projects created in the university makerspace by students:

- Printed a 6-foot replica of the founder of Voodoo Manufacturing: https://voodoomfg.com/

(probably used the software from We the Rosies)

- Lots of the architecture students will come in and print crazy structures.
- Often get good percentage of traffic from researchers
- New structures for preventing colony collapse in bees
- Researcher printed 100 small brown turtles and put them in the field as a way to track interactions with real turtles
- Gigantic models of pollen- scientific models for the institute of genomic biology
- Printed something for an Australian company who needed something shipped in the U.S.- the all stars TV show- printed them out

Only 5% of our traffic are businesses or start-ups building prototypes- this is anyways a small percentage of the need. They don't push for those users because people already have a mental block about what to make. Challenge is imagining what you can do with it. The makerspace tries to lower barriers to entry around using the tech. Majority of students who get an orientation on 3D printing in the space don't actually come back because they are intimidated or don't know what they would do with the tech.

This hasn't really been discussed in the lab- since most of the traffic is individuals doing stuff for themselves, they haven't had to worry about this. No one has ever asked them except for a few corporate or prototyping design. Some companies have asked about making sure not to share specific proprietary files. Student designers may need to sign an NDA or something like this. Ted's impression is that universities tend to care more about research projects when it comes to IP and specifically, ones that are completed by grad students and post-docs. Except for posting a policy of no weapons allowed, they haven't really addressed the IP issue.

9.4.9 Kevin (Interviewed 12/15/18)

All of the tools that Smithsonian is developing is fully open source- so they can be used for educational and commercial purposes. However, the data that they create (3D scans) because of Smithsonian policy is not fully in the public domain. That's something that's above his pay grade. They do make the 3D scans available for download, but unless there are SD609 restrictions, which refers to a Smithsonian directive which has specific reasons why they wouldn't make things downloadable. For example, human remains, objects of cultural sensitivity, objects of repatriation. Each Smithsonian museum can make these decisions individually.

But the vast majority of scans are available for the public under the Smithsonian's terms of use, which boils down to, educational, non-commercial use. So there's no commercial use that's allowed for the 3D data that they create, but the software they dev is fully in the public domain.

Software development- Kevin and team are creating the 3D metadata model which defines the capture event itself in granular detail so that even after team isn't around, a future researcher can look at a 3D scan of a research site that doesn't exist anymore or an object in the collection and in order for them to make confident decisions based on the data, the metadata model is important. Smithsonian recently released its first metadata model to the public, which then informs its 3D repository. The Smithsonian has an advanced system that allows it to preserve video and imagery, but nothing that allows it to preserve 3D data. So creating open source 3D repository for this, with several automated modules: 1) automated processing tool (in development) it's not push button and does all the processing, but the vast majority of time that his team spends comes down to the processing, not the scanning, so preparing a file for a viewer, A/R or VR, 3D print etc. is what's really time consuming and complex- a technical job which requires a fair amount of expertise. It's one step closer to automation; 2) authoring tool which will standardize how Smithsonian will tell stories with the models, so that they acknowledge 3D viewers and 3D platforms will evolve. Want to create story components in a 3D scene in a standardized way so that they can automate it to create content to different platforms. Viewer currently being used will now will probably go away in 5 years, so setting themselves up for extensibility to many platforms. Developing API that will deliver content to any platform that leverages 3D data, but also the stories around the scenes.; 3) storytelling tool- for the 3D viewer that's departure from the 3D viewer that they developed with Autodesk- want to be able to be used across objects or a collection of objects- fully open source as well.

9.4.10 Nick (Interviewed 1/15/19)

When Neil Gershenfeld published his book on Fab Labs, Nick was inspired. He was unaware of the open source movement and 3D printing until that day in 2013 when he saw the video between Richard and Ivan creating hand for Liam. That YouTube video mentioned putting the design online and was aware that device could be useful for kids and adults. Nick had this on his mind- he was procrastinating on his course, so instead of preparing for his class, he looked at comments on the original YouTube video and added his own- he noticed that there were quite a few people that mentioned that they would be willing to do this or wanted to get involved in creating prosthetics for other people who needed them.

"I created a Google Maps mash-up on a whim that morning and I put my own post into that comment stream and it said- ok makers, if you know someone that needs a hand, put a pin on this map and if you have a printer and you want to help, put a pin on this map. It was really a thought experiment except that it was public and global." And as the YouTube video went viral, more people started putting pins on the map. There were 7 that night, 70 in 6 weeks and people started calling me and saying, what do we do? Of course, I had no idea and no plan but I did make a Google+ community so that we could figure it out together. We now have 11,000+ people who are registered and there are e-NABLE chapters in 55 countries. e-NABLE is all about the designing and 3D printing of open source prosthetics.

9.4.11 Carl (Interviewed 1/17/19)

Teaches history of technology related to text:

- Interested in tech as a broad category for tech used for communications and interested in students having experiential look at this
- New 3D printing lab at Northeastern- imagining how to use it in the classroom
- Using the 3D printer to create materials used in the letter press
- Maybe image blocks, other things that don't exist and use these to print
- Considering the kinds of materials that could stand up to the pressure of a traditional printing press

How copyright relates to 3D printing- historical precedence for Carl is what is 19th century newspapers, a research specialty of his. He's been using data mining to find text printed in 19th century papers. The printing press was not new then but was democratized and led to an explosion of printing during this time period- there's an explosion of newspapers- hundreds to tens of thousands. Editors at the time mailed their newspapers to each other and looked through them and reprinted them- that was how they were made- nothing was protected by copyright or IP laws. Laws were structured to make sure newspapers were allowed to distribute knowledge- also book copyright laws for those publishing in the U.S. British authors could be reprinted with no royalties. Want to educate the population. Fair use---> it took 50 years or so from intro of the technology for the laws to catch up to allow for certain kinds of design and distribution. The explosion of the tech was way ahead.

9.4.12 Kate (Interviewed 1/18/19)

Kate didn't come from a technical background- she got into 3D printing because she was more interested in solving challenges in the developing world. Loved the customization aspect of the technology- being able to alter a small file with ease- how you can make the small adjustments that then become significant changes to a device or object to make it better.

The team she worked with at Tikkun Olam Makers showed her how it worked- showed her how CAD software worked. However, there are also still downsides to the technology, particularly around desktop printing. As far as the sustainability of materials, lots of things break or snap

Kate has always very much been for transparency, sharing→ she comes from a non-profit background- through 3D printing, she was exposed to 3D printing communities like Thingiverse and GitHub that promoted these kinds of behaviors and activities.

9.4.13 Greg (Interviewed 3/15/19)

Was fortunate enough to grow up in Southeast Kansas, where he was in a community of farmers who he considered to be the first makers, or at least the original. In the country you were on your own. If you needed to fix something, make something, do something, you had to do it yourself. These people that he grew up around in rural Southeast Kansas, were a community of farmers and makers and fixers and doers. Hard-working people.

Anyway, there's a generation of us that fell in love with tools and making things themselves and fixing their cars before the cars of today were so computerized. So, I'm just that kind of guy that liked to do things. I didn't have a lot of money. It was really about the tools. I was trying to find some hobbies. The reason I tell the story this way is, because I am a certain generation, and I grew up in a certain generation. Today's kids are growing up in a completely different time than I did. I appreciated all of these abilities we were gaining, learning to program, learning to build a computer. Learning to fix a computer, a car, your own stuff. I really felt like that died away.

I was doing digital design. I was building websites from the beginning of the internet. Taught myself to do HTML code and CSS and all that. It left me missing something, that pursuit of virtual. You know, like the drawing isn't on paper, the painting isn't with any media, it was just digital pixels.

9.4.14 Kurt (Interviewed 3/15/19)

Started 3D printing in 2013- really had a love affair with it from 2013-2018. He has been an instructional facilitator for technology and has 22 years experience. In 2013, he was feeling close to burnout, and the school district he was working in had been talking about going 1 to 1 for years.

Looking for ways to improve technology practice- 1 to 1 devices was supposed to be a catalyst for change and waiting for change and was looking for new things. Brook Drumm was selling 3D printers to educators for $500. This was cheaper than paying for a graduate course. Invested in this new tech as a catalyst for change. Bought the printer and thought he'd get into maker education. Was determined to figure out how digital fabrication fit into the classroom. Printer came- he printed a test block.

Being a facilitator was a pretty isolating experience. He's in a school district with 89,000 students- was looking for things that he could do in his school without stirring up trouble. Anxious about how to putting things forward.

Kurt is interested in how CC licensing works---> He has experimented with CC licensing over the years. Kurt did some put things on Thingiverse as not for commercial sale initially, but backed away from this because he wanted to use some of the objects he created for his own fundraising purposes.

3D printer is a proxy for a machine that makes a thing and there are lots of other machines in the world that makes things. 3D printer is a really polarizing thing in the education world- some teachers say you don't need a 3D printer. Josh wants students to be involved in the design end of the process, and to understand the post-processing that's involved. It's about adding to the sum of human knowledge.

9.4.15 James (Interviewed 4/1/19)

Hi first exposure to 3D printing was in graduate school where they were printing using powder-based printers. Didn't seem very exciting at the time, the objects had to get excavated and the prints were really fragile.

Starting into drones got him more into 3D printing- was about 4 or 5 year ago. 3D printing went hand in hand- when he got his first printer, he went down a path with ABS and PLA and it wasn't great for drone use- those materials are a bit brittle so they were good for experimenting with new forms and shapes- creating canopies and pods for covering up the electronic components. Main component of drones is carbon fiber- works really well in flat planes and uses a CNC to cut out these parts. But immediately when you start creating something with planars you have an issue with carbon fiber. 3D printing was helpful in filling this niche. Started creating camera mounting systems. Camera companies provided metal brackets, but not sturdy enough- soft flexible plastic from 3D printing was super. He does lots of design work on his own.

He publishes all of his work so that anyone can use→ his first attempt was to put the files on his site, but it was cumbersome and hard to manage, so now it's posted to Thingiverse. But it's hard to do- sometimes he'll email it to people asking. Whenever he designs a part, its often a feedback loop of design, print, modify, print. Things are ongoing versions but after 3 or 4 revisions and other tasks, he may have gotten to the point where he sends the item to the printer, but it doesn't always make it up on Thingiverse.

9.4.16 Scott (Interviewed 4/11/19)

Scott designs from scratch for anything functional and uses GrabCAD for things that he wants to incorporate into his design. Typically doesn't use existing files for functional parts- it's easier for him to start from scratch. For hard to design files, he uses Fusion 360, which allows him full control of the design process.

Scott shares within the team, but doesn't share externally. Within the team, he always wants to make sure that the versioning is correct and uses GrabCAD Workbench for this. He's developed a strict naming and assembly protocol. Initially he used Google Drive, which allowed more than one person to edit at a time and this resulted in accidentally deleting 6 months' worth of work.

With early stage design- you need to have really strict version protocol. Need the ability to roll back if something really broke.

Scott is not a fan of open source until its' a fully finished object and you want to know what people are going to do with it. People shouldn't profit off of it.

9.4.17 George (Interviewed 4/16/19)

George's entry into 3D printing was through two different projects:

1) Open CTD- This is an oceanographic instrument which measures conductivity, temperature and depth. George was rapidly prototyping parts for this project

through 3D printing. Previously, he was doing a lot with traditional woodworking and then had a few friends who got into 3D printing

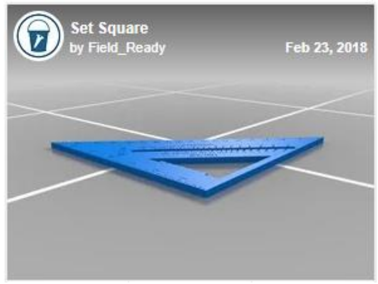
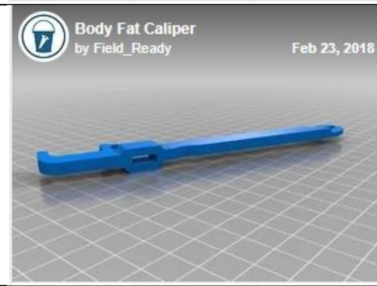
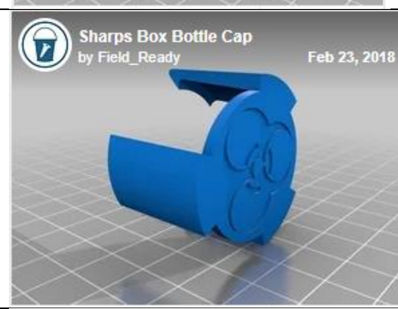
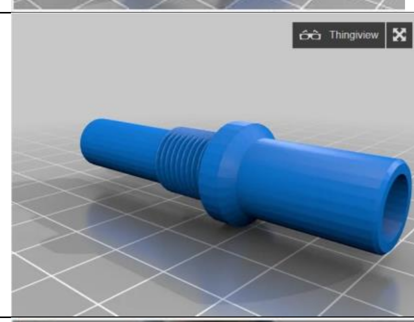
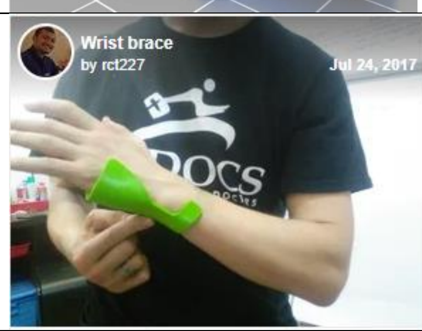
2) Ocean vegetation models- building these with 3D printing as educational models for those who don't have access to the ocean.

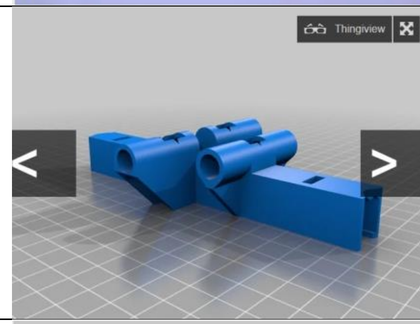
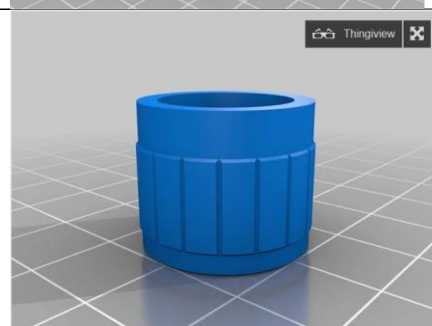
George had a background in surveying, so he had a lot of familiarity with CAD- CAD through civil engineering- it was more around street layouts, plumbing and sewer outlines, etc. Had to sit down with all the new software and learn how it functions. Also had a background in GIS, which was helpful.

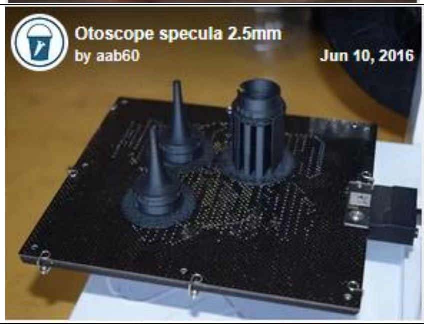
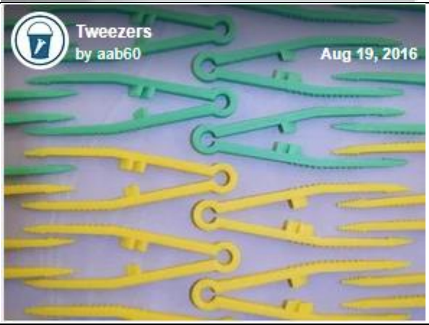
For a lot of hardware components, nuts/bolts/screws- McMaster Carr, a massive supplier of hardware has .stl files of the stuff that they sell and makes these files available to customers. So if George is working in the field on a boat and needs a spare part, can use the .stl file to print one on-site as long as he has a 3D printer with him. Folks who work in the field do this- it's a handshake agreement between the company- if you're working in the field, this isn't a problem.

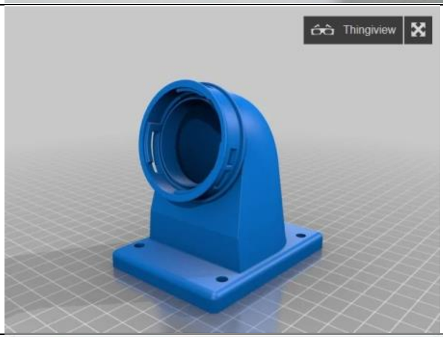
George's perspective on sharing what he creates- "Open source/ open access- ride or die!" Everything he does go to online repositories- makes sure that everything he does is open source. As a scientist- he is collecting data and generating knowledge to be shared with the world. The hardware he is developing is for citizen science and making it as accessible as possible is a key goal for him. Documentation is really important- takes longer to prepare than the actual project.

9.5 Appendix 5: List of 20 digital designs for 3D printing developed by Field Ready

set square	
body fat caliper	
cap to turn a bottle into a safe needle disposal unit	
vacuum suction pump connector	
wrist brace #1	

wrist brace #2	
part for a duoband Yagi antenna	
spare knob for clean cookstove	
kidney tray	
fetoscope	

otoscope	
otoscope specula	
finger brace	
switch for medical device	
tweezers	

ventilator connector	
dental chair pedal fix	
connector to hold IEC 309 plug socket	
ECG limb lead to secure sensors	
mechanical prosthetic	

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