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Purposes, Limitations, and Applications of 3D Printing in Minnesota Public Schools

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3D Printing in Minnesota Public Schools

by

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Chapter One: Introduction

Introduction

It was not long ago that the concept of three-dimensional (3D) printing, additive manufacturing by industrial terminology, was reserved for the rapid prototyping field of engineering and production. Interest in 3D printing, however, has grown dramatically over the past few years, (See Figure 1.1) a change set in motion in part through the expiration of patents (Schoffer, 2016). The process of 3D printing has three basic components: computer assisted (i.e. digital) design, machine equipment, and an added material. This chapter contains background to the world of 3D printing, how it can be utilized in education, and the objective and significance of wide-ranging research into selection practices.

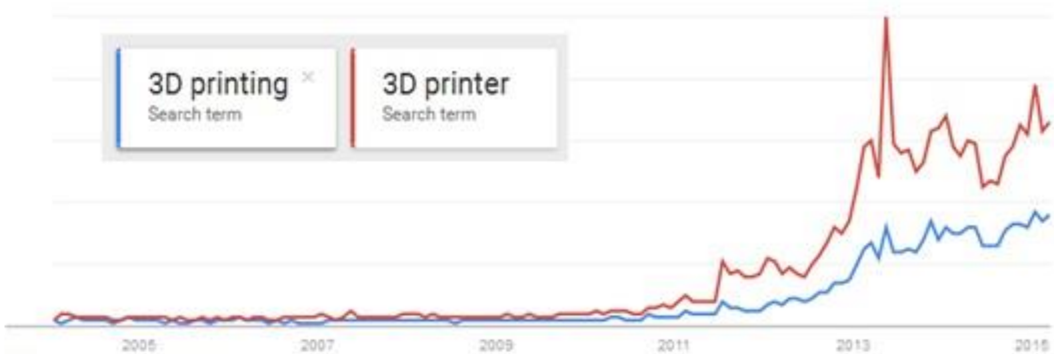

Figure 1.1: Google Search Trend Lines

Context and Background

At the inception of personal computers, it was unfathomable that every home would one day own a personal computer let alone have 1:1 initiatives for iPads or Chromebooks in many K-12 schools. Today, the 3D printing industry is a burgeoning technology field that has similarly scaled down from massive, expensive machines to desktop models available to many consumers.

There are a multitude of do-it-yourself kits and open source software available competing with commercialized all-in-one products.

Choices abound as new ways of 3D printing are developed and more and more product designers create innovative projects and materials. 3D printing processes include Fused Deposition Modeling™/a.k.a. Fused Filament Fabrication (FDM/FFF), Selective Laser Sintering (SLS), Stereolithography (SLA™), Selective Deposition Lamination (SDL) and Polyjet printing. Currently, the most affordable filament/extrusion based machines transmit the digital renderings to physical form through one of a variety of configurations: Delta, Cartesian, or the lesser used Polar and Selective Compliance Articulated Robot Arm (SCARA) styles (Campbell, 2015). Materials used include resins, plastics, nylon, metals, and a plethora of other consumables that can be extruded in minute (or massive) layers. All this to say that the world of 3D printing is ever expanding and any foray into the market requires a substantive amount of research for the discerning consumer.

The community around 3D printing is also growing exponentially. The power of the public in evolving the possibilities of 3D printing is evidenced in the RepRap project, crowdsourcing, and the global maker movement. Broad educational and consumer applications and potentially self-replicating capabilities of 3D printers are vitally important to the continued development of appropriate technology (Pearce, Blair, Laciak, Andrews, Nosrat, & Zelenika-Zovko, 2010). Creating open source machines and software is at the heart of the RepRap Project, begun in Britain, which has popularized free and open source software (FOSS) and open-source hardware for 3D printing around the globe. Harvard Professor Yochai Benkler (2006) popularized the term commons based peer production to refer to this level of collaboration.

Under this umbrella, learners work cooperatively and asynchronously to solve problems with a high degree of granularity. The use of crowdsourcing can also be seen in the crowdfunding of various aspects within the 3D design and printing process.

Crowdfunding is utilized in the production of desktop 3D printers, local production of goods, as well as subsidizing classroom purchases. Presently, Kickstarter funding opportunities abound for consumers to financially back an assortment of 3D printing related projects. Ideas range from the technical, like z-axis extensions and DIY scanners, to the eccentric, like pancake printers. Beyond micro-funding developments, the crowdsourcing model lends itself to distributed manufacturing where consumers coordinate with local producers to create goods. 3D Hubs, an online network of printer owners acts as a market for facilitating transactions between those who want to make 3D prints and the makers who own them.

In their 2015 review of printers, 3D Hubs registered 2,279 reviews on 235 different printer models (3D Printer Guide, 2015). By January 2017, the number of reviews has increased to 8,624 total reviews discussing over 1,000 different models (3D printing trends Q1, 2017). With so many options it takes a lot of research to know where to start. Online wikis, forums, and other networking and sharing sites like Thingiverse have sprung up to provide consumers, instructors, and manufacturers with access to the evolving collection of 3D printing knowledge. Public and school libraries are increasingly embracing the maker movement which often means adopting 3D printing services for their patrons and students to explore (Kroski, 2013). New Media Consortium reports name 3D printing as a technology that will influence education in the next several years (Schaffhauser, 2013).

Problem Statement

With economies of scale due to broad interest, costs of 3D technology are becoming less prohibitive to many school districts. Popular commercial models at the cheaper end of the spectrum range from $399 to $1375 (Printbot Play, 2016; Makerbot Replicator Mini, 2016). However, the multitude of options available necessitates substantive research into funding options, hardware, software, and available curriculum. Just as careful thought must be put into collection development in school libraries and overall curriculum mapping, an acquisitions and program development policy would greatly assist the procurement and ongoing practice of 3D printing in education. For educators the novelty of 3D printing must be balanced with the curricular demands of STEM, art, and other disciplines (Pannoni, 2014). Emergent research may demonstrate the possibilities of 3D printing technology to provide a unique way of encouraging innovation and problem solving skills in high school students that can meet multi-disciplinary standards and 21st century skills. The American Association of School Librarians encourages technological literacy and mastery of technology tools for inquiry learning, skills that will prepare students for new understandings in the future (AASL, 2007).

Purpose of the Study

The purpose of this paper is two-fold: reviewing the literature around 3D printing in K-12 education and assessing the current status of 3D printing in public schools in Minnesota. To complete the latter will require a survey of educators' current access to 3D printers and 3D printing resources and the possibilities for integrating 3D printing into classrooms, libraries and more. The implications for such a study may establish a base point for understanding the incorporation of 3D printing into public education. As the state and nation seek to gain competitiveness in that field, it would be helpful to utilize research comparisons from a specific place and time.

Definition of Terms

Three Dimensional (3D) printing

The layering of material via computerized control to create a three dimensional object, virtually synonymous with Additive Manufacturing

Fused Deposition Modeling™ (FDM)

The phrase and its abbreviation are trademarked by Stratasys Inc. Fused filament fabrication (FFF) was developed by the RepRap project and is used as an equivalent

Fused Filament Fabrication (FFF)

A filament (made of plastic, nylon, metal, etc.) is deposited on top of or combined with the same (or comparable) material melding the layers together by heat or adhesive

Stereolithography (SLA™)

Often referred to as resin printing, builds prints by curing a photo-reactive resin with an ultraviolet laser. The SLA abbreviation (Stereo Lithography Apparatus) however is trademarked by 3D Systems Corporation

Selective Laser Sintering (SLS)

Utilizes a laser to sinter powdered material (usually metal) which fixes the material together to create the print. The phrase and its abbreviation are trademarked by 3D systems Corporation. It is often shortened to LS.

Selective Deposition Lamination (SDL)

Utilizes regular white paper and specifically applied adhesive to build up layers of a print (Mcor Technologies Ltd, 2013).

RepRap

A community project conceived to create humanity's first general-purpose self-replicating manufacturing machine (RepRap Glossary, 2015).

Makerspace

A do-it-yourself space where individuals come together to create and learn. Referenced by several different names, but commonly used with this nomenclature within the library circuit

Fab Lab

Abbreviation for" fabrication laboratory" that is often synonymous with makerspace and emphasis a creative space for design and production

Crowdsourcing

Process of finding desired resources or other information by soliciting assistance from a large group of people, particularly through the internet, rather than through traditional means

STEM

Utilized in education to refer to Science, Technology, Engineering, and Mathematics fields

CTE

Abbreviation for Career and Technical Education, a terminology used as a synonym or replacement for vocational education

Cartesian

Use Cartesian coordinates (X,Y,Z axis to move the print head in reference to the build plate (which may also move)

Delta

Use Cartesian coordinates with a circular, stable build plate and a triangular frame

Polar

Use polar coordinates and a spinning build plate

Polyjet

Uses liquid photopolymer that cures with ultraviolet light; different from stereolithography in that material is deposited layer by layer rather than in a vat of resin

Conclusion

In this chapter, a brief history and overview of 3D printing was provided alongside the problem statement for this study. Definitions and acronyms of common and technical 3D terms were also stated. 3D printing is a dynamic field with a multitude of opportunities for matching objectives, methods, and end results. New inventions and advancements will continue to shape the development of the mechanisms, software, and community support. The fields of interest in 3D printing are as diverse as the choices of products themselves. In Chapter Two, a literature review will ascertain the current state of research into 3D printing as it pertains to education.

Chapter Two: Literature Review

Introduction

The need for consumers and educators to find current, relevant and useful information on 3D printing has opened the door for increasingly detailed examinations into the world of additive manufacturing. As it is still an emerging technology, many attempts to quantify or qualify the field start from the beginning by asking, “What is 3D printing?” In this review, the main focus is on the impacts and educational value of 3D printing. Pulling from the systematic review process of Bacca, Baldiris, Fabregat, Graf, & Kinshuk (2014) in their work on augmented reality in education, several similar questions are assessed.

Primarily, what is the current state of research in 3D printing in education? In addition, specific attention will be paid to:

A. The uses, purposes, advantages, limitations, effectiveness and affordances of 3D printing in educational settings;
B. How 3D printing is addressing needs in community settings; and
C. The evaluation methods considered for 3D printing applications in schools and libraries.

Review Methodology

Searches for research articles were completed via St. Cloud State University’s Lib Search with “3D Print*” as a subject tag query. The asterisk serves as a wildcard character that would allow for zero additional characters or more to include terms like printer(s), printing, printed etc. Results were limited by academic, peer reviewed journals, and those published within the past decade. Recency is vital with the pace of change quickly making device specific considerations and practices outdated. A 2010 discussion of two major players in the open source movement, Rep Rap and Fab@home has already become obsolete as RepRap now predominates the platform and Fab@home is completely defunct with no working web pages or access points (Pearce, et al., 2010).

The multitude of articles available, over a thousand by that exclusive criteria, belie the availability of relevant topics. The majority of results fall under hardware/software categories or exceedingly narrow interest constraints. Many reviews of the physical specifications and capabilities of 3D printers and related products (software, scanners, etc.) are eliminated via the academic journal limiter, however some articles in peer reviewed journals do demonstrate a mechanical focus not appropriate for this review. Similarly, discipline specific work in STEM, medicine and biology fields among others often analyzes a technical capacity of 3D printing rather than educational opportunity, and has therefore been excluded. Examples of research excluded for its focus on the mechanical and technical aspects of 3D printing include: Wittbrodt, Liebel, and Gehrig (2014) and Spath and Seitz (2014).

The following themes were utilized to further search, organize, and identify potentially related articles: open source, educational technology, maker movement, challenges, and policy/application. Additional research from trade periodicals has been added to provide a more well-rounded picture of 3D printing in education as an emergent topic of study.

Open Source

In sketching out a vision of the future, Eisenberg (2007) suggested that continued development in fabrication would emulate the cultural and engineering changes brought on by pervasive computing – i.e. smaller devices, integration into community venues, and copy-center availability. A decade later, it is clear to see Eisenberg’s confidence coming to fruition. Already, a large collaborative, open source community exists to make in-home fabrication possible. The aforementioned 3D Hubs is exactly the kind of local manufacturing venture that will open new doors for patrons and instructors alike.

Satwant Kaur (2012) has coined a phrase, “the Internet of 3D printed products” to describe the revolutionary capabilities of widespread 3D printing. She references a few key fields including medical applications, assistive technologies for the blind, and other custom creations, but the key takeaway is the growing simplicity of access and production. Similarly, economist Jeremy Rifkin describes the shifting manufacturing landscape as the “Third Industrial Revolution” (Spring, 2012) The desktop models mentioned in Chapter One have redefined the market and made home ownership possible. With that comes the call for open source resources which involves both hardware and software.

Just as the internet jettisoned society into the Information Age through wikis, media sharing, and instant contact, the possibilities of 3D printing may be unforeseeable and transformative. Researchers like Baden, Chagas, Gage, Marzullo, Prieto-Godino, and Euler (2015) promote the “Open Labware” concept in which universal access to product design aids customization, learning, manufacturing and global collaboration. Their review compares the possibilities of opens source 3D printing to the continued development of Linux software (p. 4). Baden et al.’s recommendations are supported by Zwicker, Bloom, Albertson, and Gershman (2015) who confirm the suitability of 3D printed parts in collegiate laboratories.

The broad applications and potentially self-replicating capabilities of 3D printers could be vitally important to the development of appropriate technology, i.e., technology that is simple and economical which can meet the variable needs of a local community. (Pearce, et al. 2010).

Futurists point to the work of the FabFoundation of MIT which brings fabrication technologies to communities worldwide to serve as a catalyst for invention. (Tucker, 2014). Continued efforts in open source availability will have increasingly positive impacts on "scientific education and research in the developing world" (Baden et al. 2015, p. 10). All this to say that the influence of 3D printing across mass culture is still evolving through the open source movement and as such, the possibilities for 3D printing to impact educational theory and practice are still growing.

Educational Technology

3D printing technology has already been referenced on the cusp of "going mainstream" within education, even though it may still be considered a growing trend by many (Horejsi, p. 10, 2014). Integrating 3D printing into education, particularly K-12 may seem most natural in the STEM fields. However, researchers have persistently demonstrated innovative ways of utilizing 3D printing in wide-ranging contexts. Kostakis, Niaros, and Giotitas (2014) designed a two part study in which high school students in Ioannina, Greece were given the opportunity to design and produce 3D artifacts containing Braille. Their constructions were then sent to blind students to enhance literacy, collaboration, and innovative capacities.

3D printing can also be used to create art sculptures and complex models of natural systems like wildfires (Reiss, Price & Evans 2014), produce interior design and fashion (Samuels & Flowers, 2015), and advance other visual and design arts **(**Spring, 2015). Educators can create project-based learning opportunities that make use of 3D printing to spark engagement with real world challenges like Sutton, Grubbs, & Ernst's (2014) cell phone case design challenge. 3D printing can also provide the basis for entrepreneurial efforts as one Minneapolis high school demonstrated (3D Printing: The Future of STEM Learning, 2014).

No matter the end product, all 3D prints begin with a design. This creation aspect plays a large role in the overall implementation of 3D printing in education. David Thornburg, co-author of The Invent to Learn Guide to 3D Printing in the Classroom: Recipes for Success, emphasizes 3D printing as an option to address the change in major educational standards from learning content to learning process (2014, p. 38).

Specific software or online tools are needed both to create 3D designs and to prepare those creations to be printed. Users' age, available computing devices, and purpose in 3D printing all inform potential design and printing software choices. Many computer aided design (CAD) programs suitable to 3D printing contain similar elements, but the graphical user interface may be tailored to a particular need or audience. Murray (2013) interviewed educators in K-12 settings and found 3D printing instructors across elementary, middle school, and high school settings. One of Murray's (2013) interviewees suggested TinkerCad as an easy-to-use design option with the youngest of students (p. 13), but it is by no means the only choice for discerning educators. A list of popularly available CAD programs, curriculum options, and resources for teachers can be found in Appendix A.

Over the past several years, many ideas have emerged for one-time projects, units, and even courses related to 3D printing. Major companies in the 3D printing community have acknowledged the need for curriculum and offer free modules for teachers to "take students through a full product development life cycle, from concept sketch to CAD design and finally 3D print" (Stratasys, 2016, p. 2). Stratasys' corporate headquarters are in Minnesota, so it's no surprise that they connect with Minnesota schools like Benilde-St. Margaret to showcase examples of how 3D printing engages learners in competitive engineering (7 3D Printing STEM projects to do with your class, 2016). Stratasys also recently visited 31 Minnesota schools to introduce students to 3D printing experiences in collaboration with Delta EMBODI, an organization with a focus on empowering African American males (DePass, 2017). Through Project Lead the Way and other STEM initiatives, curricular support for instructors is increasing across the board. Possibilities for taking advantage of open source 3D printing opportunities could be supplemented by other free or purchased curriculum.

Researchers consistently point to the potential of 3D printing to achieve otherwise improbable learning objectives. The goal of education today is to prepare 21st century learners but that means preparing students for a world of unknowns. Baden et al., explained, "One pervasive issue in building a sustainable research infrastructure and scientific culture in resource-challenged countries is a perceived limit on career choices afforded by higher education" (2015, p. 9). The open-ended possibilities of 3D printing are a distinct foil to closed-box thinking at home and abroad.

Maker Movement

The White House, under President Obama's administration, launched both an annual Maker Faire and National Week of Making which highlight the growing trend towards maker culture across the nation (The White House, Office of the Press Secretary, 2016). This trend is seen in both schools and public libraries which are embracing hands-on learning opportunities that include a mix of simple design and engineering and technology driven activities like 3D printing, robotics, and coding (Compton, & Walker, 2014).

With so many potential uses, it may eventually become challenging for administrators to decide which classrooms receive 3D printing technology. Evan Barba's (2015) take on the 21st century shop class explores how many are rethinking the traditional focus of career and technical education (CTE) commonly associated with construction, mechanics, and agriculture. The core tenets of making, which Barba describes as, “hands-on and problem based learning, design and systems thinking, technological know how, and a do-it-yourself (DIY) attitude” are well fitted to the possible learning opportunities of 3D printing as a new concentration within CTE. (2015, p, 79).

Another idea is to make such resources universally available in a space like a library on academic campuses, or in the learning commons of a K-12 school. Libraries are in a unique position to offer 3D printing support across various disciplines because they are often centrally located and utilized by both formal learning groups and individuals. Librarians have long advocated for inclusion of new technologies in collection development and 3D printing can be an exciting addition to a makerspace or fab lab environment (Kurt and Colegrove, 2012). As a rapidly increasing interest area, libraries are responding with no shortage of questions and Heather Moorefield Lange (2014a) provides some basic preparation for instituting new policies, learning new equipment, and finding the money for experimentation in her analysis of makerspace case studies.

In another example, a public library in Louisville, Kentucky began its foray into the maker movement, which included 3D printing, through a grant program and a focus on technology workshops for teens. What they found however, was that whole families and adult community members were interested as well and thus added new programs to meet the burgeoning and diverse interest. (Dixon, Ward, & Phetteplace, 2014). Their experience speaks to the growing attraction and hype around 3D printing especially for those who might otherwise not have access (GOING 3-D!, 2014).

Beyond schools and libraries, 3D printers have the power to bring people together for a common goal. E-NABLE, a collaborative group of volunteer 3-D printers, has helped to create nearly 1,000 low-cost prosthetics for children, “helping them gain independence and win acceptance from their peers”. (Wallace, N. 2015). Locally, elementary students donated 3D printed bowls they designed to an Eden Prairie event raising awareness around issues of hunger (Wennerstrom, 2016). These examples of giving-back bolster the possibilities of creative generosity and the opportunities for connecting skills and tangible products to educational goals like citizenship and community building. Despite the many benefits however, there do exist challenges for anyone thinking of integrating 3D printing into their instructional repertoire.

Issues and Challenges

Recent case studies found that 3D printers have been implemented in a variety of libraries with minimal to no training, so it isn’t surprising to find that training remains a key challenge to successful utilization (Moorefield-Lang, 2014b, p. 72). Though a great deal of support exists within the Free and Open Source movement, for educators the time investment in learning the ins and outs of mechanical systems may be an ineffective tradeoff for the more expensive, commercialized systems. One of those systems, Makerbot, even assists schools with micro-funding equipment through DonorsChoose.org.

If one has money and skills, there may still be hazards to consider. Intellectual property concerns are understandable as the ease of 3D printing may prompt the sharing and downloading of proprietary information into custom, self-made replicas. Bigger threats include the ability to

3D print potentially dangerous products such as Defense Distributed did with their Liberator gun model in 2014. (Chastain, 2014, p. 17). Others have followed suit prompting calls for regulation and legal ramifications. On the production side, some researchers also suggest “caution should be used when operating some commercially available 3D printers in unvented or inadequately filtered indoor environments” as a result of emissions of ultrafine particles particularly FFF printers utilizing ABS (Stephens, Azimi, El Orch.& Ramos, 2013 p. 339). More research needs to be done in each of these areas to respond to societal demands and safety.

Policy and Application

In several studies, recommendations for scenarios involving 3D printing have been established. In the field of education, suggestions include integrating Open Labware concepts into curriculum at an early age, establishing professional development trainings that use hands on learning, supporting greater access to 3D printing in education, and incentivizing open source creations (Baden et al., 2015 p. 10). To realize Balden et al,’s suggestions would require engaging multiple stakeholders in longitudinal experiences to test and confirm the benefits of 3D printing in education.

Toward that end, Senvol, an additive manufacturing analytics company, lists seven supply-chain situations that can benefit from the introduction of 3D printing:
high manufacturing costs, high inventory cost, long lead times, supplier sourcing issues, remote locations, high import/export costs and the necessity for improved functionality (Kerns, 2015). These concerns are not unique to the production environment, and transferring the terminology used in business may help the development of standardized processes for evaluation of the efficacy and necessity of 3D printing in the third industrial revolution. Educators similarly face

financial burdens of updating curriculum and supplies across disciplines as well as navigating procedural processes for requisitioning materials that could someday be downloaded and produced on-site.

Gaps in Research

Continued research is needed at a variety of levels. However, the largest gap this researcher found is in the lack of evaluation methods for 3D printing resources. Individually, reviews on most products can be found, but there is not a systematic review process in place for educators and other community members to utilize in finding the options that best meet their needs. Additionally, the studies included tend to be mostly review and descriptive studies with few experimental studies. The issue here is in being able to attribute the utilization of 3D printing with measurable outcomes.

Conclusion

3D printing has been touted “as epoch-making as Gutenberg’s printing press” (Smith, 2014). The research uncovered attests to that exclamation as the possibilities seem endless. There are benefits and challenges that must be weighed when considering the investment nature and continual consumable costs of 3D printing opportunities, but in the following chapters this study aims to offer organized processes for analysis and application. Chapter Three address the research and survey methodology and the significance of this paper’s contributions to the field.

Chapter Three: Research Methodology

Introduction

3D printing in education is the core theme of this paper, therefore the following research was grounded in efforts to establish greater interaction and dialogue around 3D printing and related endeavors particularly as they relate to schools and libraries. Currently, there is a lack of data around how many school have 3D printers, although some estimates suggest close to a half a million units would be sold in 2016 with around 5,000 heading to schools (DeNisco, 2015). This chapter describes the regional survey methodology and significance.

Survey Objectives

The survey (See Appendix B) was designed to answer the following primary question: To what extent do Minnesota educators value and use 3D design and printing technologies in public schools? Secondary objectives included:

1) Identifying specific school demographics (question 3, 4)

2) Determining what 3D printing resources educators have access to (questions 1, 2)

3) Determining the type of 3D printing, hardware, software, and curriculum used (questions 8-11)

4) Evaluating opinions on usefulness of 3D printing in education and the disciplines most aligned with the integration of 3D printing (questions 5, 7)

5) Determining if there is a relationship between demographic patterns and access or barriers to 3D printing technologies. (Cross break analysis of question 3 and 4 with questions 1, 2,and 6)

6) Determining if there is a relationship between access to 3D printer(s) and perceived usefulness in education. (Cross break analysis of questions 1-2, with question 5)

Survey Methodology

The target population for this survey included all administrators in Minnesota public schools, and includes educational leaders with a range of titles, e.g. principal, program administrator, and director. This community of leaders was chosen because of the broad knowledge they possess regarding purchases and practices within their school and district and because they are ideally positioned to respond to outside research requests. The sampling frame was generated from the Minnesota Department of Education-Organization Reference Glossary (MDE-ORG) which lists email contact information for public school administrators. A random number generator was used to scale back the total list of roughly two thousand administrators to a representative sample of fifty administrators (Research Randomizer, 2016). The researcher eliminated any selections whose public district policy disallows outside graduate research. Minneapolis Public Schools, for example, specifies that Master's degree proposals are not accepted because of the volume of requests they receive (Minneapolis Public Schools, n.d.).

Survey invitations were emailed to site administrators with the enclosed cover letter as the body of the email (See Appendix C). The directive of the email requested completion by the recipient, however, there were no prohibitions on forwarding the email to staff who might lead site programming around 3D printing if applicable. The survey was entirely anonymous and any identifying information provided in open form comments was not published. All questions and response items were numbered for survey coding. After data entry was completed the list of administrator contact information generated for the sample was deleted.

Timeline

The initial stage of surveying for this paper was completed in the Fall 2016 semester after prior Committee Selection, a Preliminary Conference, and Institutional Review Board (IRB) approval (see Appendix D). The proposed timeline for research was adjusted after an IRB delay and as a result of a low response rate on the initial survey request. Survey email invitations were sent in October with a requested submission date of October 30th. As adequate responses were not generated in the initial timeframe, follow up emails were sent to all administrators selected for participation in November 2016. A second round of random sampling was not undertaken as the second wave of survey requests yielded additional responses. Subsequent data analysis and written conclusions took place from December 2016 through March 2017 in anticipation of a final defense in the Spring 2017 semester.

Significance

For some technology choices, the options are clear. Most 1:1 initiatives choose either iPads or Chromebooks for their schools. There is no such dichotomy at present in the 3D printing realm. Having clear resources backed by evidence is key to funding, effective implementation and appropriate advocacy. The survey will provide a clear picture of networking possibilities. While anonymous, survey respondents will have access to view the choices and processes of others exploring this field.

Summary

This chapter provided the survey objectives and methodology as well as reasoning behind this research and its contribution to the field. Targeted sampling frames were used to identify administrators. Consenting individuals completed closed-ended survey questions on the accessibility, value, and use of 3D design and printing resources. In the next chapters, the findings of this survey, analysis of the data, and suggestions for further research will be laid out in their entirety.

Chapter Four: Findings

Introduction

The findings below represent results of research that occurred in the Fall 2016 semester. The purpose was to identify the extent to which Minnesota educators are concerned with or utilizing 3D printing technologies in public schools. This chapter will lay out the results of the survey of Minnesota school administrators regarding 3D printing realities and perceptions. The full survey response data is available in Appendix D and additional reflection on the survey responses will be discussed in Chapter Five.

Response Rate

Out of 50 public school administrators emailed, only 5 completed the survey initially. A follow-up email generated 6 additional responses for a total of 11 responses or 22 percent. Therefore, the actual rate was much lower than the ideal, anticipated 40 percent response rate. Nevertheless, it provided a small glimpse into the broad spectrum of experiences with 3D printing.

Demographics

Respondents for the survey (full data available in Appendix D) included administrators from a variety of school demographics, including a heterogeneous mix of student grades served and overall school size. All respondents represented schools with less than 1000 students in population (Figure 4.1), but spanned all ages from all inclusive K-12 schools, to elementary and high school populations (Figure 4.2). The respondent who elected "other" to the question of grade levels served in school population, as seen in Figure 4.2, specified a 7-12 student body.

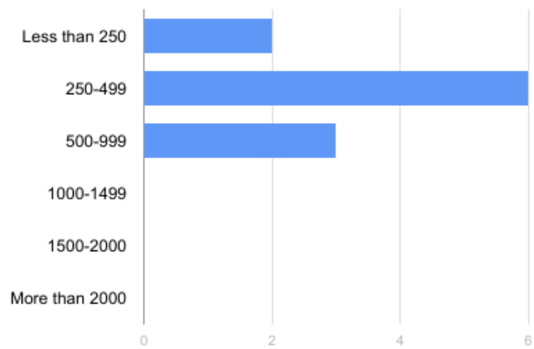

Figure 4.1: What is the approximate student population of your school**?**

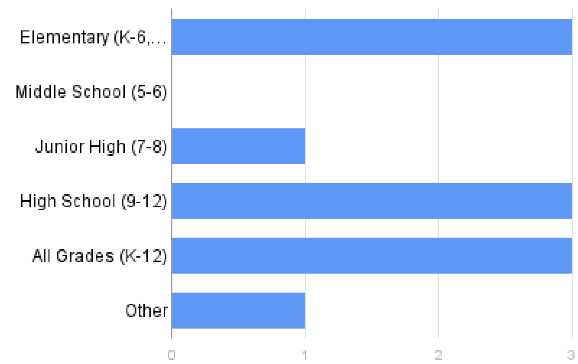

Figure 4.2: What is the grade level of students in your school?

Access and Ownership

Three out of eleven respondents said they had a 3D printer in their school, one of whom indicated they had three at their site. An additional two respondents indicated that students had access to a 3D printer in their district either in a different elementary school or high school setting (Figure 4.3). The primary barrier to access was "funding" with the "skill to operate", "curriculum", and "interest" following in subsequent order of influence. Not surprisingly, the two respondents who indicated that having access to a 3D printer was "not important" also indicated that "interest", or in one's own words, "no need" was a primary factor preventing them from obtaining a 3D printer (Figure 4.4).

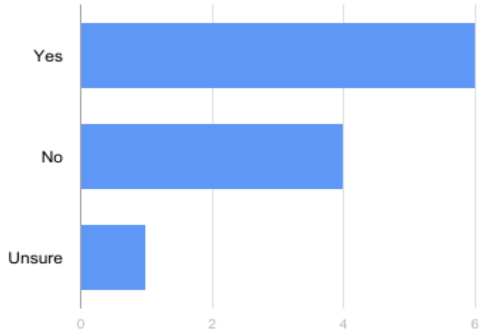

Figure 4.3: Do your students have access to a 3D printer in your district?

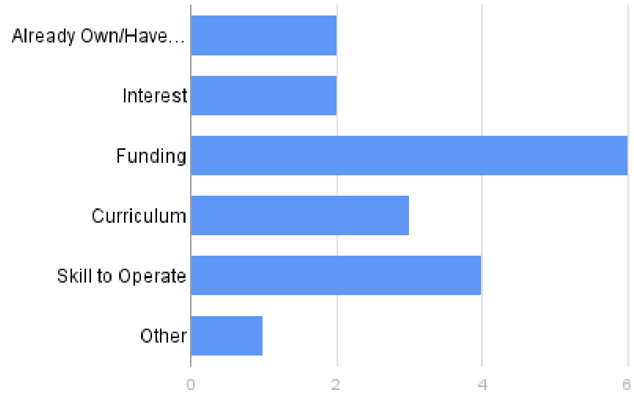

Figure 4.4: What barriers are preventing your school from obtaining

Multidisciplinary Benefits

In terms of the most useful disciplines in which to integrate 3D printing, responses were all across the board. Some respondents did not fully complete the 1-7 ranking, and the question had the lowest response rate overall with only 4 respondents completing the full ranking and an additional 4 only completing a partial ranking. Nevertheless, "Engineering" was ranked number 1, or *Most Beneficial* by 3 respondents, with "Industrial Technology", "Library", and "Mathematics" each selected by a single respondent as a *Most Beneficial* as well. Overall, "Engineering" and "Library" received the most votes in the numbers 1 and 2 selectors at the *Most Beneficial* side of the spectrum with 4 votes each.

On the other hand, most subjects, apart from General Science, also received at least one vote ranking it as the "Least Beneficial". The subject with the highest number of votes on the *Least Beneficial* side was "Computer drafting/Design". Different opinions were also shown amongst the three respondents who indicated their schools owned 3D printers.

	Least Beneficial **7**	**6**	**5**	**4**	**3**	**2**	Most Beneficial **1**
Industrial Technology	2	0	0	0	0	1	1
Computer drafting/design	1	3	0	0	1	1	0
Art	1	0	2	2	0	0	0
Library	1	0	2	0	0	3	1
General Science	0	2	0	3	2	0	0
Engineering	1	0	2	1	1	0	3
Mathematics	2	1	0	1	2	1	1

Figure 4.5: Please rank the use of 3D printing in the following disciplines with 1 being Most Beneficial and 7 being Least Beneficial

Selection and Use

In terms the hardware, software, and curriculum used in 3D design and printing, responses were limited to those respondents who indicated that a 3D printer was owned by their school, i.e. most administrators indicated the following questions were “Not Applicable”. The types of 3D printers owned included stereolithography and selective deposition lamination (Figure 4.6). The design software used included AutoDesk which offers a line-up of Fusion, Tinkercad, and 123D Design (many of which are available free to use for educators and students) and OpenScad which is also a free software (Figure 4.7).

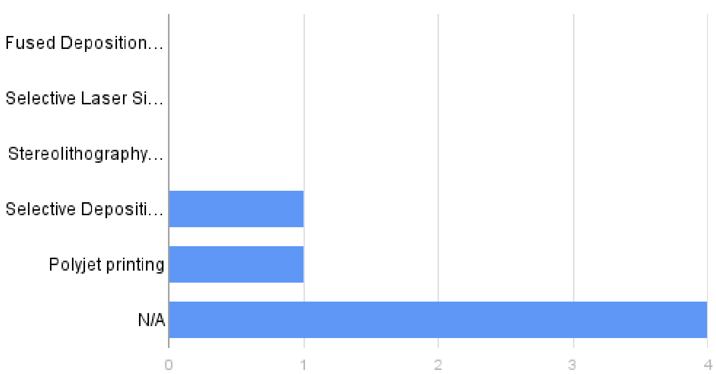

Figure 4.6: If you own or have access to a 3D printer what type is it?

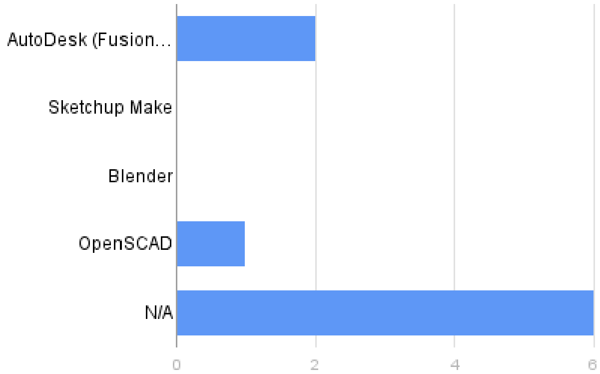

Figure 4.7: If you own or have access to a 3D printer what software or design applications do you use?

Curriculum selection was reported as a mix of “Purchased” (2 respondents) and “Open source” (1 respondent) as shown in Figure 4.8. Each of the selection questions allowed respondents to select more than one option in the case they had multiple printers, users, etc., however each respondent only selected one option.

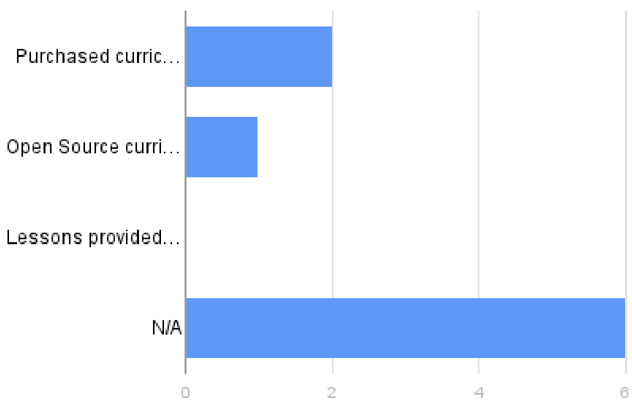

Figure 4.8: If you own or have access to a 3D printer what curriculum do you use?

Conclusion

This chapter delineated the findings of survey research into the value and use of 3D printing in Minnesota schools. Respondents represented diverse school settings with varied ages and total populations. Though only a few respondents owned 3D printers (and could provide data in terms of device and design application selection) the valuation of 3D printing both in general and across disciplines demonstrates a wide body of thought around using 3D printing in education. In the next chapter, reflection on the response rate and analysis of the survey results will be followed by suggestions for future research and the options for disseminating this study.

Chapter Five: Conclusions

Introduction

In analyzing the findings from chapter 4, the researcher must acknowledge both the limitations of the study in terms of response rate and sampling errors, including selection bias, which influence the external validity of the survey. In conjunction, analysis of the results provides opportunities to derive recommendations for future research and practice. This literature review and study provides a starting point for evaluating 3D design and printing opportunities in K-12 education as a growing technology field and educational trend

Discussion of Results

To begin with, the survey response rate was lower than ideally anticipated. The researcher believes this response rate could be due to a variety of explanations not the least of which was a lack of incentive to use valuable time for assisting an unknown graduate research project. Understandably, administrators have many critical tasks at hand during the school year and completing an anonymous survey, however brief, is not a priority with consequence. As a self-administered survey, the onus for completion rested solely on the recipient with only a single follow-up email as reminder. Additionally, though the researcher eliminated results from school districts with well known outside research policies and prohibitions, other district administrators invited to participate may have similarly avoided participation due to internal policies that are not publicized or widely available. This non-random exclusion in the selection process also affects the transferability of the results to the general population.

In addition to the low response rate, the results of the survey are influenced by the nature of the respondents. Administrators are the easiest connection point to understanding trends in K-

12 schools, however, they may not be the experts in their building when it comes to specific technologies, in this case: 3D design and printing. Two respondents indicated they were “unsure of brand” for 3D printers that were owned by the school while a third listed Makerbot, a popular commercial brand.

Also surprisingly, the types of printers respondents indicated they owned were selective deposition lamination and polyjet printing. In contrast, the most commonly available desktop models for 3D printing appears to be Fused Deposition Modeling™/ Fused Filament Fabrication according to online reviews like 3D Hubs and general consumer availability. More accurate results in terms of the name of the brand, the curriculum, or the type of printer may have been garnered from those who are involved in their use directly.

No patterns emerged to tie demographic results with 3D printer ownership in a statistically significant way. However, the disparate perspectives show that varied possibilities of integrating 3D printing exist and more information can be gathered in the future to better understand the scope of 3D printing in education.

Limitations

A number of design and implementation factors, including those mentioned above, influence the validity and reliability of the research results. Namely, a larger survey sample size may be needed to draw conclusions which most accurately represent the use and value of 3D design and printing throughout public schools in Minnesota.

The structured questions and brevity of the survey were also intentional to maximize participant response. However, these aspects also limited the scope of understanding the current status of 3D printing use. In particular, the classes or extracurricular groups that have used 3D design and printing and the success of those implementations. Remedies to these limitations are discussed more in the succeeding sections on implications for educators and administrators and recommendations for future research.

Implications for Educators and Administrators

The diverse responses garnered through the survey offered a few perspectives on the usability and need for 3D printing in education. Actual examples of decision making processes and hands-on implementation around 3D design and printing may be a better precursor than the statistical results available here for introducing the topic. However, based on the resources identified in this paper (see Appendix A) and evidence of use demonstrated by the survey, educators and administrators have access to the tools and reviews necessary to implement 3D design and printing as they see fit. While it may not work for everyone, growing emphasis on experimentation and preparing students for future problem solving makes the leap to 3D printing both a curricular and extracurricular opportunity.

Recommendations for Future Research

After reviewing the results of this survey, it is clear that more research will be necessary to continue monitoring the evolving trend of 3D design and printing in education. While it is far from widespread, there is evidence in both the survey results and the researcher's own observations that schools are weighing the benefits and challenges of integrating this innovative option into curriculum and extracurricular learning.

For future surveys, follow-up questions based in this research could be directed to new audiences such as teachers, librarians, or students to ascertain their perspectives and valuation of 3D printing in education. More in depth approaches utilizing case studies and observational methods may be appropriate in building a more complete picture of the ways in which 3D design and printing benefits K-12 learners.

The exclusion of private and independent schools from this exploration was a limiting design choice that was intentional based on the desired parameters of this project, but also derived in part from the availability of population data and contact information publically available through the Minnesota Department of Education. A broader research question might consider the opportunities available to all Minnesota students. The researcher believes interest in 3D printing in K-12 education will continue to grow and as such more research from academic institutions, state and local education agencies, and commercial companies is likely to be conducted.

Sharing Research Results

The results of this research will be made available in St. Cloud State University's Institutional Repository and available online. All research participants were provided the researcher's contact information as demonstrated in Appendix C. Additional opportunities to share through professional conferences, webinars, and local professional learning communities will be assessed as they arise.

Personal Reflection

The researcher's own anecdotal experience in two unsurveyed districts reflects the popularity of 3D design and printing as an educational choice. In seven Minnesota schools personally visited that implemented 3D printing, all seven used FDM/FFF style printing and used commercially available desktop models. Apart from this difference, observations mirrored the findings of this study as to the variability of across demographics (both elementary & high school) and disciplines (curricular integration and standalone service in a library media center). The researcher also attended presentations about maker culture and the use of 3D printing in education at the recent 2017 LibTech conference and 2016 ITEM (Information and Technology Educators of Minnesota) conference which attest to the growing audience for 3D printing.

Conclusion

In this study, available research into 3D design and printing integration in education was presented in a literature review and a new survey study attempted to quantify the use of 3D printing by K-12 public school educators in Minnesota. The results of both demonstrated the novelty of 3D printing as well as the variety of functions it can serve in an educational setting. For individuals and institutions seeking to begin their foray into the world of 3D printing, resources can be found in online communities, with commercial vendors, and through a growing network of experienced educator users. As with many educational ventures, there are as of yet, no clear answers as to what works best and a variety of factors may influence potential usage. The researcher recommends reviewing this brief analysis or other introductory explanations as a decision making background for purchasing, operation, and collaborative opportunities.

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Appendix A

3D Design and Printing Applications
Blender
https://www.blender.org/

SketchUp Make
http://www.sketchup.com/products/sketchup-make

OnShape
https://www.onshape.com/edu

AutoDesk
Fusion 360
http://www.autodesk.com/products/fusion-360/students-teachers-educators
TinkerCad
https://www.tinkercad.com/
123D Design
http://www.123dapp.com/design

3D Tin
http://www.3dtin.com/#

OpenSCAD
http://www.openscad.org/

All About 3D Printing
https://all3dp.com/best-3d-printing-software-tools/

3D Printing Curriculum and Resources for Educators

Maker Bot
http://www.makerbot.com/uses/for-educators

Stratysys
http://www.stratasys.com/industries/education/educators/curriculum/introduction-to-3d-printing

SeeMeCNC
https://www.seemecnc.com/pages/seemeeducate

Education in 3D
https://sites.google.com/a/sabinepass.net/education-in-3d/home

Mouse
https://mouse.org/about and https://create.mouse.org/

Appendix B

Survey Questions

The actual survey was delivered in a web-based format

1. Does your school own a 3D printer?

(Check one)________yes _________ no
1 2

If yes, please state how many: ____

2. Do your students have access to a 3D printer in your district?

(Check one)________yes _________ no _________ unsure
1 2 3

If yes, please explain: ____

3. What is the approximate student population of your school?

_______ 1. Less than 250
_______ 2. 250 - 499
_______ 3. 500 - 999
_______ 4. 1,000 - 1,499
_______ 5. 1,500 - 2,000
_______ 6. More than 2000

4. What is the grade level of students in your school? (Check one)

_______ 1. Elementary (K-6, K-5, etc.)
_______ 2. Middle School (5-6)
_______ 3. Junior High (7-8)
_______ 4. High School (9-12)
_______ 5. All grades (K-12)
_______ 6. Other: Please explain

Please indicate the number you feel is closest to your experience

5. How important is having access to a 3D printer in your school?

very important somewhat important not important

1 2 3 4 5

Comments: ____

6. What barriers are preventing your school from obtaining a 3d printer? (Check all that apply)

_______ 1. Already own/have access
_______ 2. Interest
_______ 3. Funding
_______ 4. Curriculum
_______ 5. Skill to operate

______ 6. Other: __________________

7. Please rank the use of 3D printing in the following disciplines with 1 being Most Beneficial and 7 being Least Beneficial.

______ Industrial Technology
______ Computer drafting/design
______ Art
______ Library
______ General Science
______ Engineering
______ Mathematics

Comments: ____

8. If you own or have access to a 3D printer what type is it? (Check all that apply)

______ 1. N/A
______ 2. Fused Deposition Modeling™/ Fused Filament Fabrication (FDM/FFF)
______ 3. Selective Laser Sintering (SLS)
______ 4. Stereolithography (SLA™)
______ 5. Selective Deposition Lamination (SDL)
______ 6. Polyjet printing
______ 7. Unsure/Other (specify) ___________________

9. If you own or have access to a 3D printer what brand is it? (Check all that apply)

______ 1. N/A
______ 2. Unsure of Brand
______ 3. D.I.Y/Open Source
______ 4. Commercial Brand (Please List) ___________________

10. If you own or have access to a 3D printer what software or design applications do you use? (Check all that apply)

______ 1. N/A
______ 2. AutoDesk (Fusion, TinkerCad, 123D Design)
______ 3. Sketchup Make
______ 4. Blender
______ 5. OpenSCAD
______ 6. Other : _____________________

11. If you own or have access to a 3D printer what curriculum do you use? (Check all that apply)

______ 1. N/A
______ 2. Purchased curriculum
______ 3. Open Source curriculum
______ 4. Lessons provided by the owner/operator/distributor of the 3D printer
______ 5. Other: __________________

Appendix C

Cover Letter

Dear Principal,

How do you spark students' ingenuity and prepare them for the 21st century? Schools, libraries, and businesses are increasingly utilizing 3D printing to meet curriculum goals and community needs. I am surveying public school administrators in Minnesota to assess the prevalence of 3D printing in today's K-12 education.

I invite you to take a brief survey on 3D printing in education and provide any tips or suggestions on how you select and integrate innovative technologies in your district. The 10 question survey should not take you longer than 5-10 minutes to complete.

Participation is voluntary, so you can choose not to answer some questions, or not to participate in the project. Additionally, you can withdraw at any stage of the project without being penalized or disadvantaged in any way.

Because of your experience and perspective in the field of education, your answers are very important. All answers will be held in the strictest confidence: no individual's particular answers will be identifiable, and results will only be shared in aggregated form. The web-based survey provider I am using, Survey Monkey, details their privacy and confidentiality practices here: https://www.surveymonkey.com/mp/policy

All results, including any resources shared by respondents, will be available via my final paper or upon request.

Click **HERE** to take the Survey. Submitting the questionnaire indicates your voluntary consent to participate. In order to have your responses included in the results we publish, please complete by October 30th.

Thank you for your time and I look forward to hearing your thoughts!

Amy Fettig
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St Louis Park, MN 55426

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Appendix D

Institutional Review Board Approval

ST. CLOUD STATE
UNIVERSITY
EDUCATION FOR LIFE.

Institutional Review Board (IRB)

720 4th Avenue South MC 204K, St. Cloud, MN 56301-4498

IRB PROTOCOL DETERMINATION:
Exempt Review

Name: Amy Fettig

Address 1816 louisiana Ave S,
St. Louis Park, MN 55426 USA

Email: ajarends@stcloudstate.edu

Project Title: The purpose, Limitations, and Applications of 3D Printing in MINNESOTA PUBLIC SCHOOLS

Advisor Dr. Marica Thompson

The Institutional Review Board has reviewed your protocol to conduct research involving human subjects. Your project has been: **APPROVED**

Please note the following important information concerning IRB projects:
- The principal investigator assumes the responsibilities for the protection of participants in this project. Any adverse events must be reported to the IRB as soon as possible (ex. research related injuries, harmful outcomes, significant withdrawal of subject population, etc.).

- For expedited or full board review, the principal investigator must submit a Continuing Review/Final Report form in advance of the expiration date indicated on this letter to report conclusion of the research or request an extension.

-Exempt review only requires the submission of a Continuing Review/Final Report form in advance of the expiration date indicated in this letter if an extension of time is needed.

- Approved consent forms display the official IRB stamp which documents approval and expiration dates. If a renewal is requested and approved, new consent forms will be officially stamped and reflect the new approval and expiration dates.

- The principal investigator must seek approval for any changes to the study (ex. research design, consent process, survey/interview instruments, funding source, etc.). The IRB reserves the right to review the research at any time.

If we can be of further assistance, feel free to contact the IRB at 320-308-3290 or email ri@stcloudstate.edu and please reference the SCSU IRB number when corresponding.

IRB Institutional Official:

Dr. Latha Ramakrishnan
Interim Associate Provost for Research
Dean of Graduate Studies

OFFICE USE ONLY

SCSU IRB# 1632 - 2042	**Type:** Exempt Review	**Today's Date:** 10/20/2016
1st Year Approval Date: 10/17/2016	**2nd Year Approval Date:**	**3rd Year Approval Date:**
1st Year Expiration Date:	**2nd Year Expiration Date:**	**3rd Year Expiration Date:**

Appendix E

Survey Results

1. Does your school own a 3D printer?

Yes	3
No	8
Not Sure	0

2. Do your students have access to a 3D printer in your district?

Yes	6
No	4
Unsure	1

3. What is the approximate student population of your school?

Less than 250	2
250-499	6
500-999	3
1000-1499	0
1500-2000	0
More than 2000	0

4. What is the grade level of students in your school? (Check one)

Elementary (K-6, K-5, etc.)	3
Middle School (5-6)	0
Junior High (7-8)	1
High School (9-12)	3
All Grades (K-12)	3
Other	1

5. How important is having access to a 3D printer in your school?

2	3	0	6	0
Not Important	--	Somewhat	--	Very Important

		Important		

6. What barriers are preventing your school from obtaining a 3d printer? (Check all that apply)

Already Own/Have Access	2
Interest	2
Funding	6
Curriculum	3
Skill to Operate	4
Other	1

7. Please rank the the use of 3D printing in the following disciplines with 1 being Most Beneficial and 7 being Least Beneficial.

	Least Beneficial **7**	**6**	**5**	**4**	**3**	**2**	Most Beneficial **1**
Industrial Technology	2	0	0	0	0	1	1
Computer drafting/design	1	3	0	0	1	1	0
Art	1	0	2	2	0	0	0
Library	1	0	2	0	0	3	1
General Science	0	2	0	3	2	0	0
Engineering	1	0	2	1	1	0	3
Mathematics	2	1	0	1	2	1	1

8. If you own or have access to a 3D printer what type is it? (Check all that apply)

Fused Deposition Modeling™/ Fused Filament Fabrication (FDM/FFF)	0
Selective Laser Sintering (SLS)	0
Stereolithography (SLA™)	0
Selective Deposition Lamination (SDL)	1
Polyjet printing	1
N/A	4

9. If you own or have access to a 3D printer what brand is it? (Check all that apply)

Unsure of Brand	2	
DIY	0	
Open Source	6	
Commercial Brand (Please List)	1	Makerbot

10. If you own or have access to a 3D printer what software or design applications do you use? (Check all that apply)

AutoDesk (Fusion, TinkerCad, 123D Design)	2
Sketchup Make	0
Blender	0
OpenSCAD	1
N/A	6

11. If you own or have access to a 3D printer what curriculum do you use? (Check all that apply)

Purchased curriculum	2
Open Source curriculum	1
Lessons provided by the owner/operator/distributor of the 3D printer	0
N/A	6