# Manufacturing Jobs from Home

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# Abstract

This study deals primarily with the implementation of a network of manufacturers relying on 3D printers, CNC machines and other automated devices to perform manufacturing activities from their homes. The paper presents an analysis on the adoption of 3D printing by regular consumers, items consumers show interest in making using 3D printers as well as the incorporation of 3D printing into a business model to ensure adequate value creation and capture. A survey is performed to collect data on the demographics of possible home manufacturers and the results are analyzed to develop recommendations for the implementation of this new type of manufacturing economy.

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# 1. Introduction

In 2020, the global economy faced a lot of unique challenges, as the majority of companies advised their employees to work from home, in an attempt to curb the outbreak of the virus and protect their workforce. This occurrence spurred thought into researching the implementation of a job ecosystem reliant on entirely home-based work, specifically involving manufacturing items of value as a means of income.

This project focuses on the implementation of a framework that will enable a user-led, open approach to engaging in manufacturing activities from home using 3D printers, CNC machines, and other small to medium-sized automated equipment, with the end goal of bringing innovative products and services to the public.

A reduction in the process cost over the past few decades has made 3D printing increasingly more commonplace. The technology takes advantage of a process called Fused Deposition Modelling. This is an additive manufacturing technique that involves building parts layer-by-layer through the deposition of molten extruded thermoplastic. The extruder head is automatically controlled and guided through the use of Computer Numerical Control (CNC). FDM enables the creation of 3D objects without geometric restrictions and can produce parts that cannot be easily manufactured through other manufacturing processes.

Since the invention of 3D printing, it has been clear that the underlying technology has the ability to massively disrupt and transform the way items are produced. The technology gives people the power to quickly and easily test out new product ideas and can significantly reduce product development costs. FDM can also reduce the time it takes to produce manufacturing tools such as tooling masters, fixtures, and jigs. The list of possible applications for this technology goes on and on. In recent times, 3D printing technology has even been applied in the construction industry to manufacture 3D-printed homes.

## 2. Background

The methods by which a current, modern household acquires goods vary vastly from those used by households before 1770 [1]. This change is a result of the industrial revolution which began in England in 1760. Before the industrial revolution, the primary industry of all countries was agriculture, and the household served as the center of production. Settlements consisted of groups of 25-30 able-bodied men and their families. Each family produced its necessities through the distribution of labor based on age, strength, and skill. Families planted and harvested crops and would spin and weave fabrics into clothes.

Over time as some villages grew into towns, manufacturing gravitated towards being conducted in organized labor groups under a capitalistic structure. At this point, there was very little specialization in labor, and people worked long hours, performing various tasks, but with no rush or stress [1]. The well-being of a household was correlated with the skill level of its constituents.

Between 1770 and 1790, massive disruption was brought to the textile manufacturing scene through the use of spinning jennies, water frames, mules, as well as steam power. More inventions for use in other manufacturing activities followed suit and new methods of production were imagined. Initially, this rise in innovation brought great wealth to all; however, led to massive unemployment over time due to the capitalist nature the economy had developed [1]. Spinning and Weaving jobs had become automated, so fewer people were required and children could also be hired to operate the machines and paid fractions of the wage an adult would make.

Although the initial wave of poverty and unemployment continued for quite some time, specializations in both skill and occupation began to emerge from progress made in machine innovation and the natural sciences. These new specializations created a lot of jobs; however, activities that were previously performed in the home such as brewing, weaving, and cheese-making were transferred to industrial settings where specialists could be employed to create products on a much larger scale, using expensive equipment owned by capitalists. Although this change in trend led to higher quality items for all, the household had ceased to become the production center, and the wellbeing of the household no longer relied on the production capabilities of its individuals, but rather the opportunities they were able to seize to perform work and earn income.

In modern times, people don't work for 16 hours of the day like in 1760, and children are no longer active members of the workforce; however, there is a lot much more competition and stress involved in work. Covid 19 particularly brought to attention the reliance most individuals have on performing economic activity outside their homes. People couldn't make as much money anymore due to lockdown restrictions.

Of course work from home did exist before Covid 19; however, this was mainly in the form of providing services. We see this with platforms such as Amazon Mechanical Turk [2], a crowdsourcing marketplace where companies can outsource work to remote workers. A lot of other companies which provided services or work done digitally/ online were able to proceed, almost unhindered during the height of the Covid 19 lockdowns. That is because people could still use their computers for work. This stark realization led the head researcher on this project to question the feasibility of implementing jobs from home where people not only provided services but could create value in physical items and make money off the process.

The Manufacturing jobs from home IQP aimed to reduce the reliance on industrial manufacturing settings and develop a framework for workers to be able to manufacture items from home using 3D printers and other CNC machines. This framework would ideally foster a sense of community within home manufacturers and enable them to share and transfer knowledge in an easy, constructive way. Apart from these benefits, we see the implementation of such a home-based manufacturing network as the creation of a new economy. An economy that we believe will empower the masses by engaging them with means of production. This economy is likely to improve worker flexibility and satisfaction, provide means of extra income for some individuals and spur on competitive production and innovation.

# 3. Literature Review

## 3.1 Consumers and adoption of 3D Printing

Despite the growing popularity and importance of 3D printing technology, there is still a gap in understanding of how everyday consumers, possible home manufacturers, understand and interact with 3D printing and other associated technologies. There was a study conducted by researchers, attempting to fill this knowledge gap and empirically test how much individuals' characteristics, and their perceptions towards home 3D printing systems, can explain people's adoption of such systems in China [3]. Although 3D printing systems enable individuals to manufacture without traditional manufacturing constraints, research has shown that consumers are initially reluctant to adopt innovative products 'that provide novel benefits but involve high learning costs' [4].

The study performed in China made use of a combination of the Innovation Diffusion Theory (IDT) and the Technology Acceptance Model (TAM) to explore the factors affecting users' intentions to use home 3D printing systems. The researchers also attempted to investigate the moderating effects of an individual's characteristics (i.e. demographics) on their intention to use the system.

The Innovation Diffusion Theory(IDT), developed by E.M. Rogers in 1962, is one of the oldest social science theories. It originated in communication to explain how, over time, an idea or product gains momentum and spreads through a specific population or social system. This spread results in the adoption of a new idea, behavior, or product. People start to go about tasks differently than they had before the adoption of the innovation. The key to adoption is that the person must perceive the idea, behavior, or product as new or innovative [5]. When promoting innovation to a target population, it is important to understand the characteristics of the target population that will support or hinder the adoption of the innovation.

The Innovation Diffusion Theory establishes five adopter categories: innovators, early adopters, early majority, late majority, and laggards. Each category has different techniques which can be used to stimulate innovation adoption. Different stages lead to adoption under the IDT. The awareness of the need for innovation, the decision to adopt or reject an innovation, initial use, and continued use of the innovation [5]. Based on the IDT, the stages leading to adoption are in turn influenced by five factors: relative advantage, compatibility, complexity, trialability, and observability.

The Technology Acceptance Model (TAM) was introduced by Fred Davis in 1986 and has been one of the most influential models of technology acceptance. This model is somewhat similar to the Innovation Diffusion Theory; however, in the TAM, the two primary factors that influence an individual's intention to use new technology are perceived ease of use and perceived usefulness. There is a complementary relationship between both theories because they share conceptual bases, making it appropriate to use the two models in tandem.

In the study conducted in China, the researchers used the perceived ease of use, and perceived usefulness from the Technology Acceptance Model. They slightly modified the Innovation Diffusion Theory by replacing the complexity construct with perceived ease of use from the TAM and replacing relative advantage with perceived usefulness from TAM. Observability was excluded from the research due to the inconsistent findings on its effects on the adoption of new technologies in previous studies cited by the researchers. The researchers were also curious about the levels of amusement generated from home 3D printing and added a new construct to the mix - perceived enjoyment.

Age was found to be a significant positive moderating effect between perceived ease of use and intention to use 3D printing systems at home. Although older people had more negative feelings towards the perceived ease of use, it was found that age was not a moderating factor in determining the perceived usefulness 3D printing brings, nor was age a significant moderator in the perceived compatibility of 3D printing at home with the survey participant's lifestyle. It was also found that age did not play a role in participants' perceived enjoyment from the use of a 3D printing system at home. This suggests that older individuals could have high intentions to adopt home 3D printing, but may struggle with using the technology easily, probably due to older users having less experience with technology as a result of declining absorptive capacity.

According to the researchers, male participants also showed higher levels of perceived ease of use compared to females. This result was further validated by the data collected on perceived enjoyment, in which males were more likely to enjoy the process of using a 3D printing system at home. Gender is not found to have significant moderation effects on the relationships between perceived usefulness and intention to use. Gender is also not found to have significant moderation effects on perceived compatibility with the user's lifestyle. This suggests that perceived usefulness and perceived compatibility were equally important for both males and females.

The data collected by the researchers also showed that education had no moderating effect on the other factors influencing the adoption of the technology. This suggests to me that education levels do not play a key role in determining the probability of acceptance of home 3D printing, but rather certain people, regardless of educational background will develop high levels of interest in home 3D printing. It was discovered that design background is a highly important moderator for perceived ease of use, perceived usefulness, and perceived compatibility. The researchers found that these factors are far more important for designers, compared to non-designers. The researchers believe that this significant difference is due to the differences in skill level possessed by designers as compared with non-designers. The data did not suggest that a participant's design background had a significant moderating effect on perceived enjoyment in their intention to use a 3D printing system; however, it was noted that participants with a design background valued usability, usefulness, and compatibility far more than how enjoyable the use of a home 3D printer is.

## 3.2 Items Produced by Consumers with 3D Printing

When conducting my research, I also found it invaluable to determine what kind of object users may want to make and possibly manufacture. A study conducted by researchers in the United States attempted to discover what kind of objects consumers with a 3D printer at home would want to create [6]. This study utilized faux 3D printers planted in 10 homes and relied on the 28 study participants to engage in cultural design probes. These probes encourage participants to actively record their thoughts and ideas for the use of their imaginary 3D printer over 4 weeks. The data generated provided key insights into people's lives and thought processes in regards to the ability to manufacture products within their homes. The cultural probes provided the participants with an easily understandable way to engage in the making process and to design objects without constraints, and without the necessary skills and software required to operate a 3D printer. Placing a real 3D printer in participants' homes could have hindered the participants' creative thought process and limited their design ideas.

Although 3D printing as a concept frees makers from constraints, affordably priced 3D printers have various limitations, such as availability of printing material(filament), print bed size, printing time, and availability of software for design and printing. Even with these limitations, consumer 3D printer purchases are on the rise. The consumer 3D Printing market was valued at $ 1.7 Billion in 2017 and is anticipated to grow at a compound annual growth rate of over 22% during the forecast period 2018-2023 [7].

Most participants in the study had earned at least a bachelor's degree. Participants' household salaries ranged from 35k to 200k US dollars. During recruitment, participants with little to no prior knowledge of 3D printing were selected. The cultural probes had pre-defined categories participants were not made aware of. The categories were: Giving and Helping, Replacing and Repairing, Creativity and Crafting, Customizing and Modifying, and an Experimental category that contained questions about Health and Wellbeing and about 3D printing outside of the home. Participants placed the faux printer in a location they would not forget about in their home. The 4-week experiment had an equal number of prompted and unprompted design exercises. In weeks 5 and 6, participants' data was aggregated and semi-structured interviews were conducted to understand why objects were suggested for production and what purposes they would serve.

The households created 1021 prompted objects and 144 unprompted objects. Open coding analysis was performed to determine the trends in participant object creation. The items suggested were classified by their characteristics, material properties, the item category according to Amazon.com, as well as the intended use of the objects.

From the data gathered, it was apparent that participants wanted to print materials currently beyond the capability of 3D printers, with the most commonly combined materials being wood and metal, as well as metal and plastic. These items often had moving mechanical parts which may not be possible to print.

A majority of the suggested products were items already available for sale, so the objects were separated into 36 different categories. The 5 most common suggested item categories, in order, were: Home & Kitchen, Tools & Home Improvement, Toys & Games, Kitchen & Dining, and Sports & Outdoors products. People seemed primarily interested in replicating existing items, even when completing design prompts related to creativity and crafting. There was some demand for improving or repairing existing objects, and very little for creating entirely new products.

Objects that were intended to be replicated were primarily common items such as spatulas and coffee mugs. 11% of the prompted objects, and 5% of the unprompted ones, included embedded mechanical parts, electronics, or other hardware. Although these are unlikely to be 3D printable, these ideas provided valuable insight into the production desires of individuals. In addition to replicating everyday objects, participants were interested in making replicas of unique items already in their possession, or available to them, to have an additional copy or give one as a gift. Beyond duplicating existing objects, 15% of the prompted and 1% of the unprompted requests involved improving, repairing, or customizing an existing object. While participants most created or modified existing objects with the faux 3D printers, some designed new objects. A lot of these new objects would require substantial design or 3D modeling to create, and unfortunately, some participants did not give adequate levels of details on their new creation idea, possibly making it difficult to turn these ideas into reality. These requests pushed the boundaries of 3D printing. Although some of the suggestions were almost impossible to make  (e.g., weather-changing devices and disease curing nanobots), a lot of the other suggestions were spurred by dissatisfaction with current products on the market (e.g., a posture aid, garage tools), and could be made at home.

Participants expressed their ideas in plain writing, drawings, and photographs of example objects. Few participants generated 3D sketches of their ideas, and most lacked the necessary Computer-Aided Design skills required to model their object. Although some requests could be satisfied using stock 3D objects from online printing repositories, a lot of the objects would require modification/ redesign even if the model was initially imported from the internet. This finding indicates that there is a need for alternative 3D design/ customization tools which make 3D modeling more accessible. For example, it was observed that a lot of participants wanted to start with an existing object but change the size. Easy-to-use software for scanning with a mobile phone and editing the generated 3D model could be a possible solution to this problem.

Although a lot of items suggested are outside the scope of current 3D printing technology, this research work provided me with some insight into the manufacturing expectations users might have. This work spurred my decision to include laser cutters and other CNC machines which could be used on a wider range of materials and lead to a larger variety of possible objects for at-home manufacturing.

## 3.3 Incorporating 3D Printing in the Business Model

Although originally used mainly for rapid prototyping, 3D printing technologies have progressively taken a more important role in various manufacturing processes. It is now possible to use 3D printers not only to prototype but also to manufacture tools and molds used for 'traditional' manufacturing [8]. In modern times, 3D Printers can even be used to fabricate final products. It's interesting to note that some 3D printers even 3D print other 3D printers.

In the late 2000s, the cost of 3D printing had become low enough to justify direct manufacturing with 3D printers. The quality was also of high enough standards to validate directly manufacturing of final products with 3D printers, skipping the use of other traditional manufacturing processes using molds, casts, or machining.

Around 2015, the adoption of direct manufacturing significantly increased due to the rise of online 3D printing platforms. Companies such as Materialise Onsite [9] enable individuals to create 3D printed objects and prototypes in various materials and finishes. The company manufactures the items and ships them to the customer. Materialise Onsite assures short lead times for even the most time-critical of projects.

The process of 3D printing is made to be very flexible and transferable due to the digital nature of 3D models. There is consensus on the value and potential of the technology; however, the question remains of whether 3D Printers will become commonplace devices used for home manufacturing. The main arguments against the use of 3D printing for home manufacturing are cost, low print quality, and limitations in materials that can be used [8]. There is also the issue of the lack of enough regular use of the technology to justify its purchase/ use. It is interesting to note that similar arguments were used against the Internet in its advent, yet the Internet has gained widespread use and acceptance. This serves as a supporting counterargument against the infeasibility of home 3D printing.

This project aims to justify the implementation of a system where people manufactured from home. To do this, I believe we have to view the individual and indeed the network of home manufacturers as a business. “Whenever a business enterprise is established, it either explicitly or implicitly employs a particular business model that describes the design or architecture of the value creation, delivery, and capture mechanisms it employs...It also outlines the architecture of revenues, costs, and profits associated with the business enterprise delivering that value [10].”

A Business model for bringing 3D printed products manufactured from home by individuals would need to be built on a logical plan for bringing products to market and turning profit. Business scholars have postulated various definitions of what constitutes a business model; however, there is consensus on four key components: value proposition, value creation, value capture, and value delivery[8].

Value creation involves increasing a customer’s perceived worth of a product or service offered. When value creation increases, people’s willingness to pay for said value increases as well; however, this does not mean that the company creating the value can raise its prices to capture it [8]. A network of home-based manufacturers has the potential to create significant value; however, it will be critical to establishing a business model capable of adequately capturing this value.

3D printing technologies can be involved in different stages and to varying extents within the manufacturing process. We can classify the types of production possible with home-based manufacturing into different stages of manufacturing, in which users may be able to participate in: rapid prototyping, rapid tooling, and direct manufacturing [8]. With these categories and our knowledge of people’s production desires, we can develop an analysis on likey categories in which home manufacturing has the opportunity to both create and capture immense value.

When integrating 3D printing into rapid prototyping processes, the build turnaround could be significantly cut down. This affects the value proposition of the business, as ideas can be materialized in a shorter time; however, 3D printing in rapid prototyping does not have as visible of an effect on value creation and value delivery. This is because the item created is just a prototype and may not make it to market, or be mass-produced in 3D printed form. With that being said, 3D printing for rapid prototyping does have the ability to alter the business cost structure, and so when done at the right price point, will increase value capture. Bringing rapid prototyping to consumers could spur on a lot of innovation; however, in the case of our home manufacturers, I'm not sure they would benefit from this. Rapid prototyping companies have existed for years, and even if home manufacturers are capable of undercutting large companies price-wise, it is unlikely that this system would be able to meet high volume production demands. This indicates that at-home rapid prototyping is best suited for lower volume production.

Similar to rapid prototyping, rapid tooling accelerates the production process but does not radically change it [8]. With lower cost and quick turnaround time, rapid tooling with 3D printers primarily serves the purpose of making it cheaper and easier to create variants of a product. For example, different molds can quickly be made to offer a wider variety of products. For home manufacturers, we do however run into the issue of volume again, as 3D printed tools are usually just a part of an overall larger more traditional manufacturing process. If rapid tooling is implemented for home manufacturing, it is likely to involve some other form of value addition/ manufacturing taken on by the home manufacturer. Even with a variety of 3D printers and CNC machines, it is unlikely a home manufacturer can create rapid tools for use in other manufacturing activities without also buying more expensive equipment for traditional manufacturing such as injection molding. Rapid tooling is just a small part of a larger, possibly costly production process. With that being said, I do believe that at-home rapid tooling is possible but will likely not be an automated process (apart from creating the tools).

Direct manufacturing with 3D printing opens up more possibilities in terms of creating a business model. The unique advantages of 3D printers can be leveraged to increase value propositions, as product/ service offering could be increased. Coupled with 3D printing's full customization capabilities, it is possible to create more value for customers, and new pricing models can be developed to better capture value. A network of 3D printers makes the business model fluid and capable of incremental change geared towards optimizing the business. Direct manufacturing increases value delivery, as this could enable the network of at-home manufacturers to serve any niche regardless of how small it is due to the elimination of the costs which made serving the niche unviable in the first place.

With traditional manufacturing, fixed costs such as machinery and set-up costs or storage costs are significant, while marginal cost is often fairly low. This is quite the opposite with 3D printing, which generally involves lower fixed costs to purchase equipment, but higher marginal cost [8]. This alteration in cost structure could be advantageous depending on the volume of production. The cost structure is likely to be a disadvantage in high volume production unless the value created from customization is so high that the marginal cost of manufacturing can be passed onto consumers during value capture. I believe that this is likely to be the case if home manufacturers made low volume, high necessity items such as spare parts or medical devices.

At-home direct manufacturing has clear advantages in value creation; however, in value capture, there are some concerns, specifically concerning profit allocation. If the equipment used by the home manufacturers isn't owned by them (as is likely to be the case in some instances if this system is implemented), the home manufacturer will need to relinquish a good portion of their profits from value capture to cover the cost of the equipment. The aim of the implementation of a home manufacturing network is to make it accessible to all, and so the concept of machine financing plans for home manufacturers is a priority; however, the profit allocation issue could make it uneconomically sound for individuals to engage in home-based manufacturing if they do not own their machines. This realization inspired the idea of home manufacturing being a government-sponsored initiative geared towards job creation, in which there is a clear revenue model that allows the government to subsidize costs without incurring an unjustifiable loss.

A home-based manufacturing initiative is likely to face several challenges in its infancy; however, this may be combated through the use of a "mobile business model" [8] in which the business can easily pivot to leverage arising profit and growth opportunities. Due to the open-ended nature of 3D printing, the business model can be capable of horizontal movement, which involves engaging new market segments/ product offerings. The business model can also be shifted vertically upstream or downstream through varying degrees of involvement of 3D printing in the different manufacturing stages.

# 4. Methodology

The goal of this study is to assess the feasibility and identify the individual's level of interest in the creation of manufacturing jobs from home, as well as the content and logistics of such an economy. Home based manufacturing jobs will encourage flexibility in working hours, spur on a competitive economy of production and could lead to an acceleration of technological innovation due to the number of people that will be capable of creating new things and finding a market for them.

To achieve this end I defined a set of objects:

1. Learn about individual's perspectives regarding manufacturing work from home using robots.

2. Identify demographics with high potential for manufacturing jobs at home.

3. Identify and discuss challenges involved in the creation of a home production economy.

4. Develop recommendations for the structural implementation of such an economy.

Through means of a survey approved by the Worcester Polytechnic Institute, Institutional Review Board (IRB-21-0566), I gathered and analyzed input from possible home manufacturers. A copy of this survey can be seen in the Appendix. This survey was integral in achieving my 4 objectives outlined below.

### 1. Learning about individual's perspectives regarding manufacturing work from home using robots.

To gather data on the level of interest and willingness to engage in at-home manufacturing I created an anonymous online survey which was sent out to as many people as possible. Apart from reaching out within my network to collect data, I also reached out through Reddit and Facebook on various online forums for work from home job seekers, unemployed individuals, and existent 3D printer owners and maker hobbyists. The decision to select these forums came about because I believe that this subset of individuals could benefit the most from the implementation of a home production economy.

To successfully propose strategies to implement such an economy I needed data on individuals' perspectives on the use of automated robotic systems to make things at home. I need to identify things they like/ dislike about the idea, their underlying expectations behind such a system, as well as their willingness to learn new skills which will facilitate the creation and ensure the stability of the proposed home manufacturing system.

2. **Identifying demographics with high potential for manufacturing jobs at home.**

I believe that my survey asked a lot of relevant questions which aided in segmenting survey participants into various demographic backgrounds such as age, income, gender, and education level. With the segmentation of demographics, I can identify key trends in demographics and their interests in manufacturing from home.

Apart from gathering this information, I also attempt to access the demographic's capability of actually following through with the intended manufacturing plan. I am hopeful that the data collected from answers to questions such as comfort using hand tools, creative abilities, and CAD familiarity will give some indicators to the individual's capabilities to successfully run a home production operation.

3. **Identifying and discussing challenges involved in the creation of a home production economy.**

I believe there will be several challenges and risks involved in an attempt to create an economy revolving around products manufactured by people from home. Possible challenges and concerns which I have identified and plan to discuss include:

a. Financial responsibility involved in providing equipment for manufacturing
b. Economies of scale and volume involved in such a system
c. Ensuring reliable quality in products manufactured
d. Creating growth and sustainability within the economy
e. Safety of individuals participating in home-based manufacturing

4. **Developing recommendations for the structural implementation of such an economy.**

With the data collection and analysis accomplished as described in the paragraphs above, I am confident I can construct recommendations on what this newly proposed economy would look like and possible steps which can be taken to ensure the success and growth of a home-based manufacturing economy.

# 5. Findings

My survey received 357 Views and was started by 216 participants; however, I only received 159 responses. That represents a 73.6% survey completion rate. Participants were from several states within the United States and various countries outside the US as well. This can be seen as illustrated below in Figures 1 and 2.

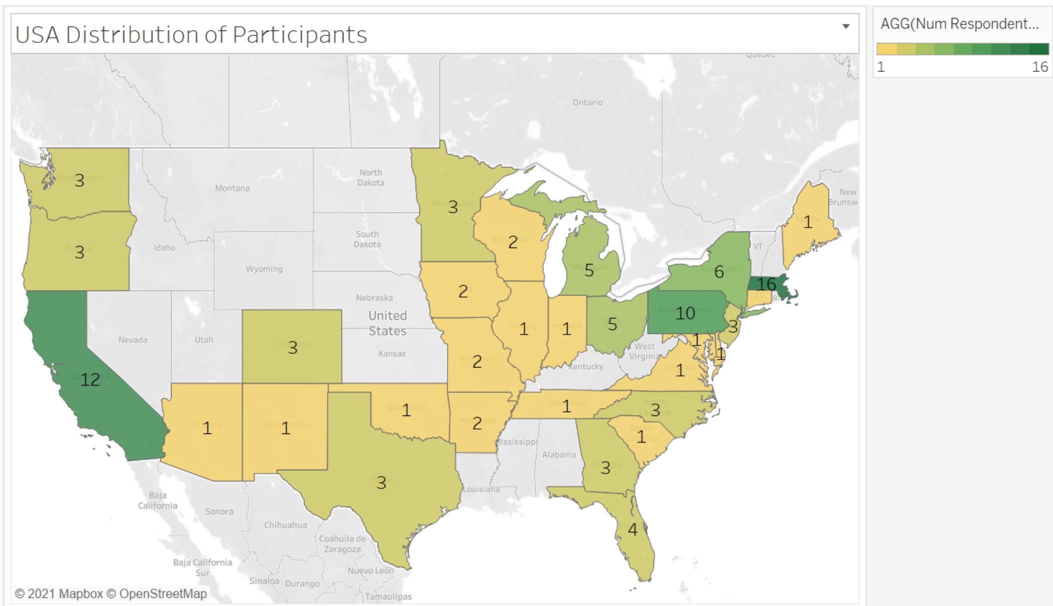



**Figure 1. Distribution of survey participants within the US**

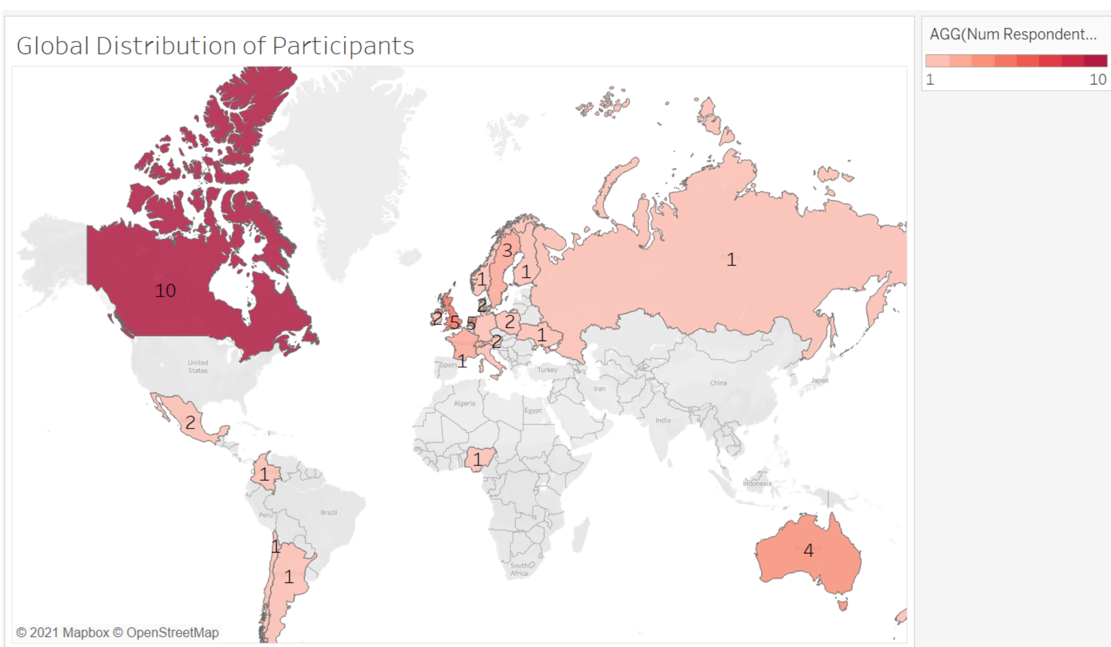



**Figure 2. Distribution of survey participants outside the US**

The main demographic data collected were age, gender, education level, and income. The distribution of survey participants based on this information can be seen in the figures below. I made an effort to increase the number of female participants in the survey, by reaching out specifically to stay-at-home mum forums and women's groups. This was because I expected the Female response rate to be lower, based on my research.

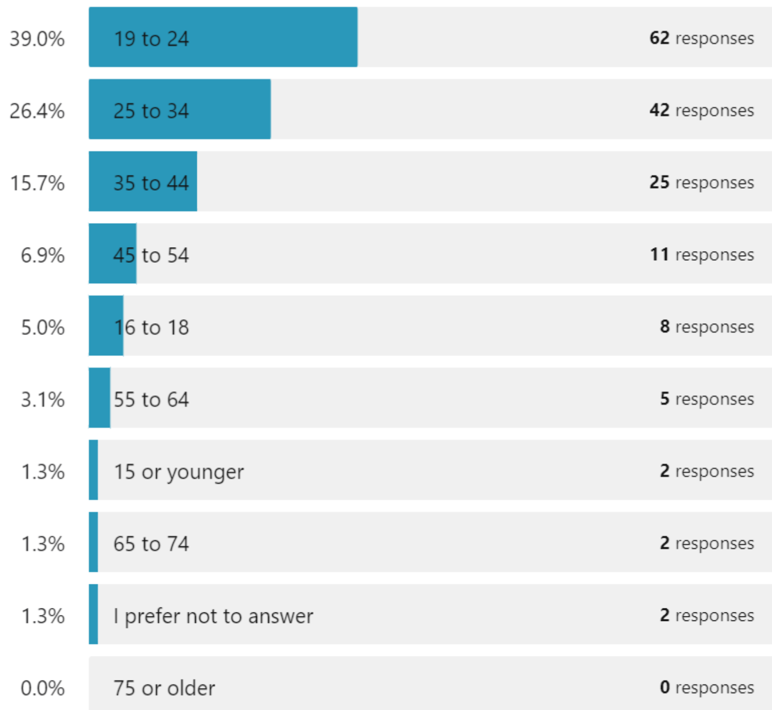



**Figure 3. Participants' ages**


**Figure 4. Participants' gender**

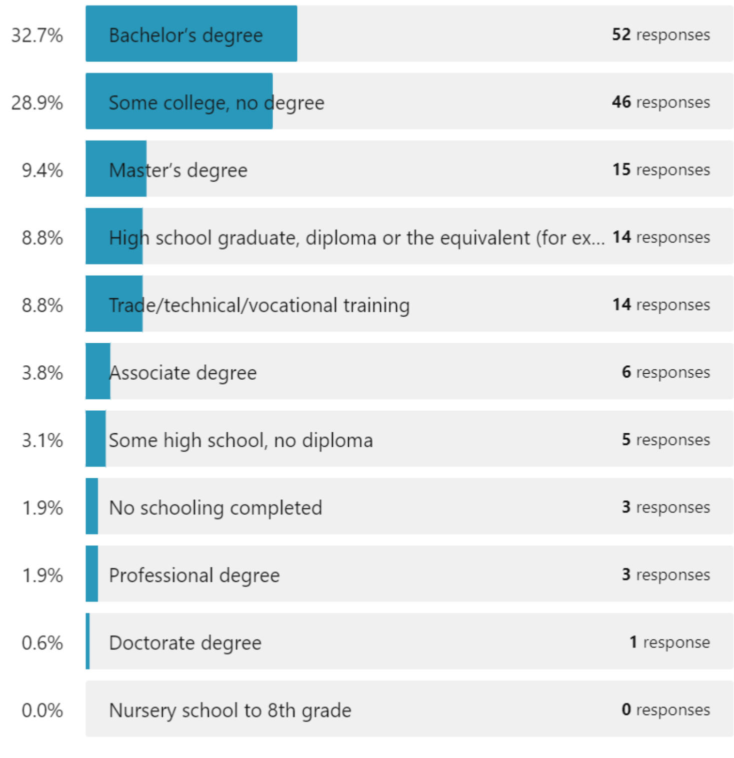



**Figure 5. Participants' education levels**

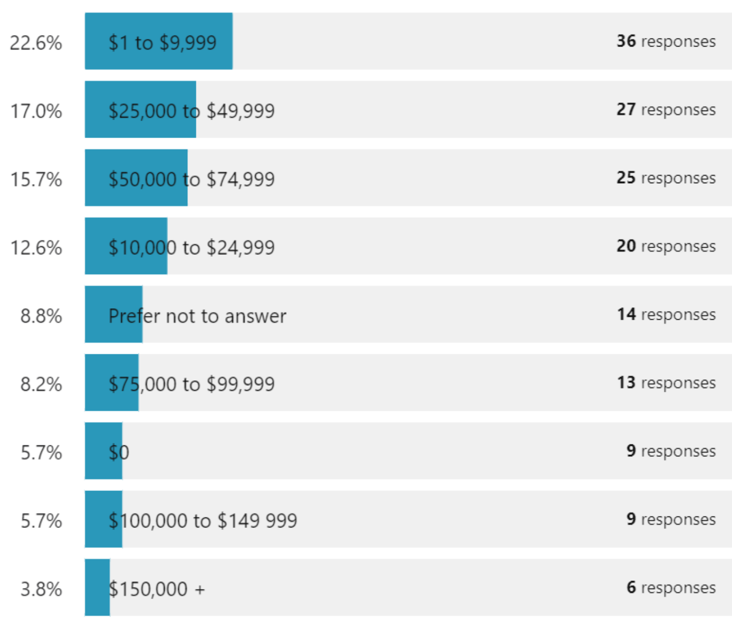



**Figure 6. Participant's income levels**

## 5.1 Computer Aided Design Competency

In assessing an individual's ability to manufacture from home, I believe the knowledge of Computer-Aided Design is essential. This element was removed in the study cited in the literature review where participants engaged with a faux 3D printer, so I decided to ask participants about their knowledge of CAD. 32.1% of respondents said they were comfortable using CAD, 19.5% said they had personally used CAD before, while 18.2% had previously seen CAD software in use but not engages with it. 16.4% of respondents claimed to be an expert at CAD software, while 13.8% had no idea what the software entailed.

When asked if they could learn to use the software 47.8% of respondents answered that they know how to Computer-Aided Design, while 42.8% claimed to be willing to put in the time to learn. 4.4% had no interest in learning, while 2.5% had no idea if they were capable and another 2.5% believed learning would be too difficult.

I focused on this second data set involving learning Computer-Aided Design. The responses were subdivided by demographics and further analyzed. The majority of participants either know how to CAD or want to learn, and the proportion of those in the know and those willing to learn is evenly distributed across age and education levels. This can be observed in Figure 7 and Figure 9 below, where each demographic variable has participants divided through the use of a color scheme with a legend.

There seems to be a trend in regards to gender. A smaller proportion of Female respondents answered that they know how to CAD, the majority fell in the willing to learn category. A higher proportion of Females also responded that they had no interest in learning CAD or that it was probably too hard for them as compared to the Male responses. Details of this can be seen in Figure 8. Similar to the researchers in China, I did notice poorer levels of interest/ participation from Females and subsequently excluded further gender-based analysis on my data.

As can be seen below in Figure 10, there seems to be a higher proportion of higher-income individuals in the $50,000- $74, 999 and the $75,000 to $99,999 income ranges who already have CAD abilities. While individuals in the $25,000 - $49,999 income range seem to be lagging in CAD knowledge, at least proportionally, compared to other income groups. This data could suggest that individuals with CAD ability are capable of earning a higher income performing traditional work.

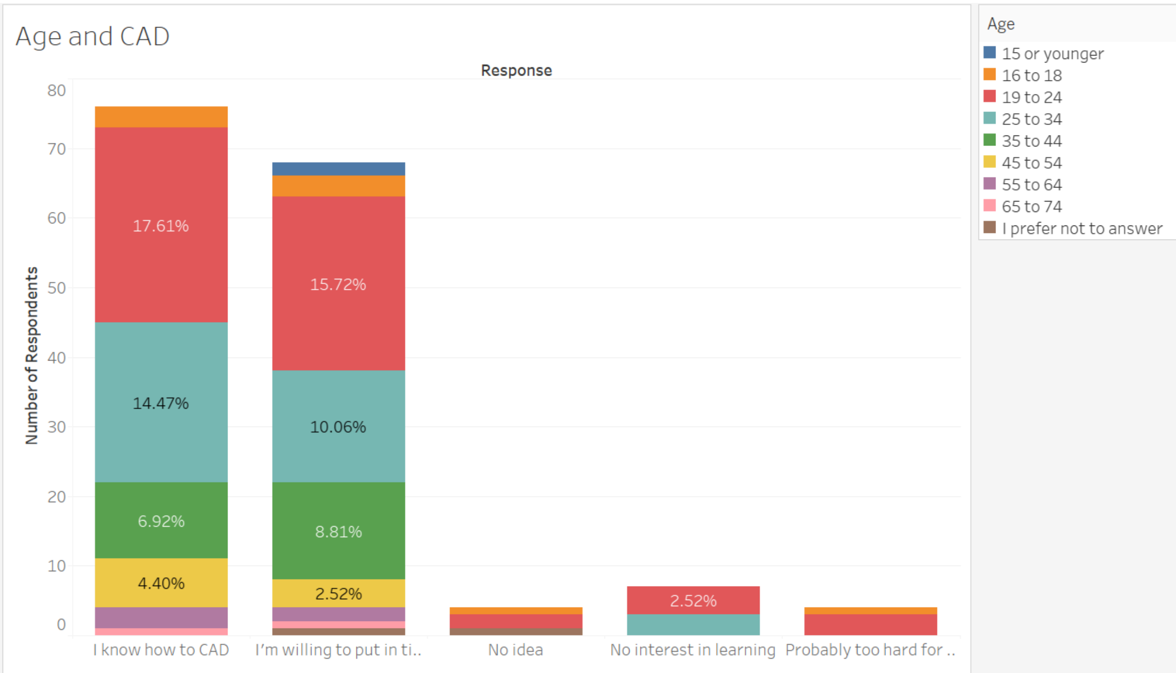



**Figure 7. Age demographic compared with CAD abilities**

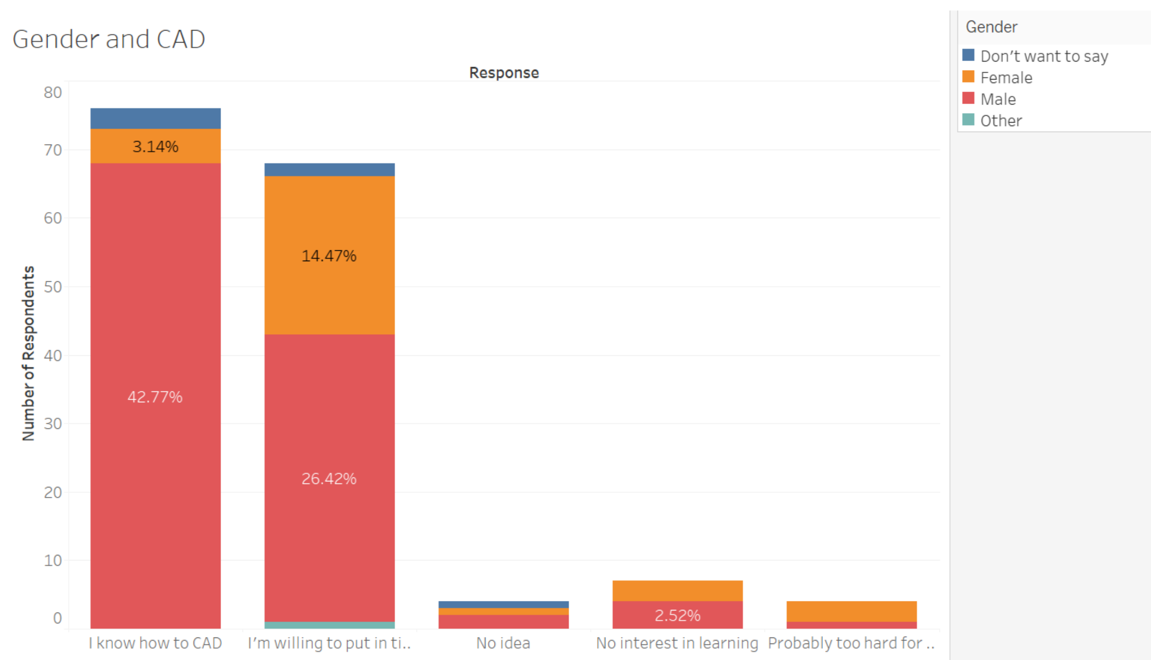



**Figure 8. Gender demographic compared with CAD abilities**

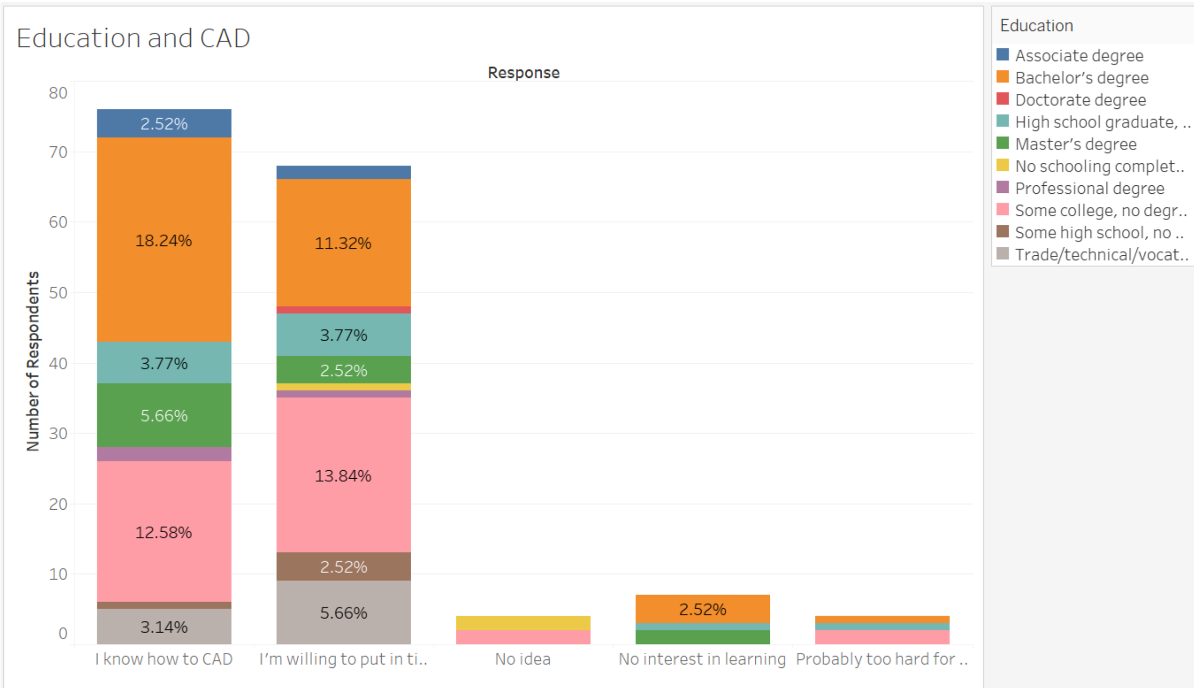



**Figure 9. Education demographic compared with CAD abilities**

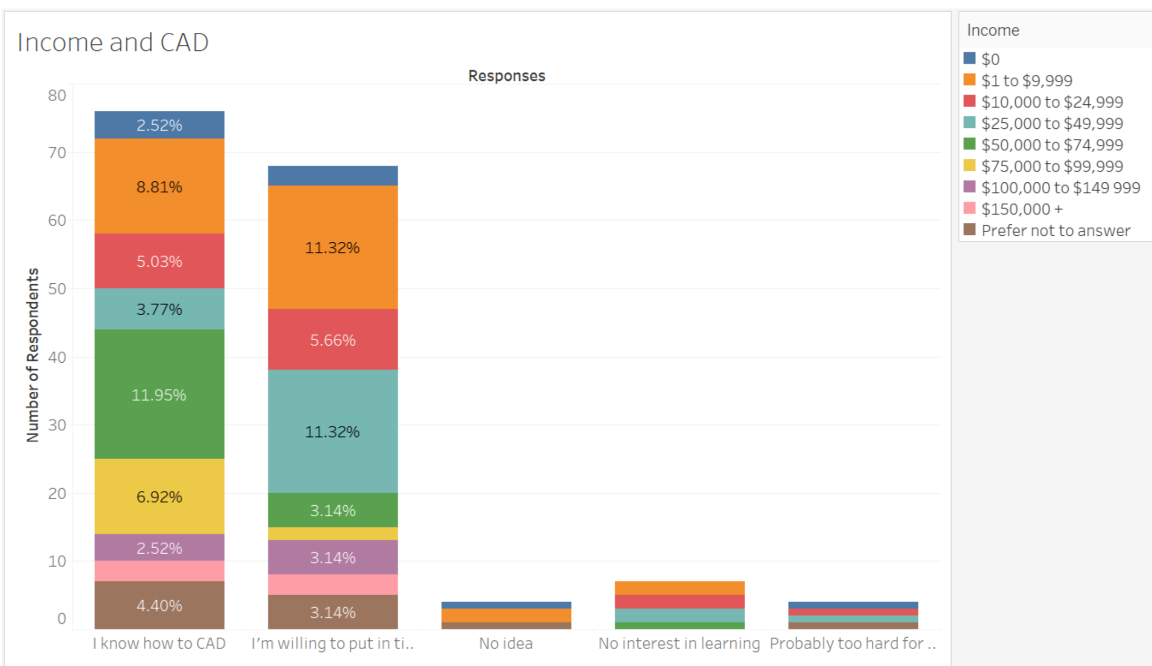



**Figure 10. Education demographic compared with CAD abilities**

## 5.2 Creativity Levels

In the infancy stage of development, a home manufacturing initiative will likely require individuals who possess high levels of creativity and making know how to facilitate innovation and fresh ideas. To assess participants on this factor, I asked if they considered themselves makers, artists, or designers and to rate their making on a scale of 1 to 10. The results of this can be seen below in Figure 11.

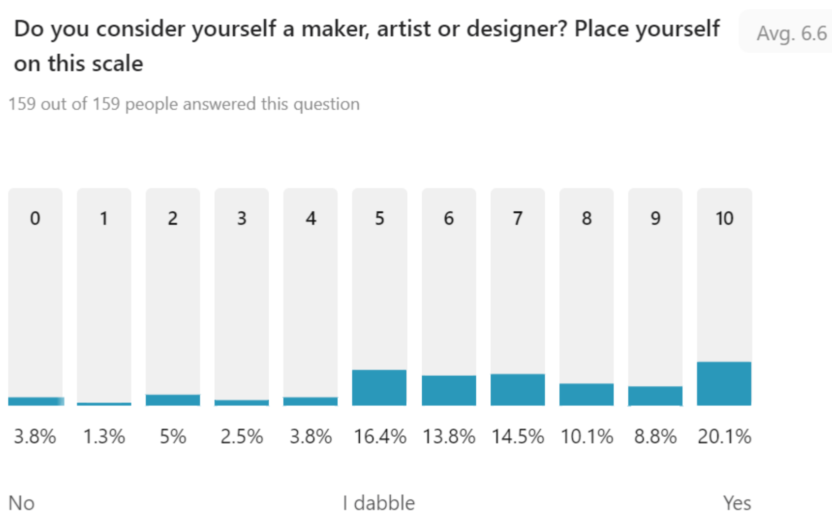



**Figure 11. Participants' level of creativity**

On average participants had a creativity rating of 6.6/10. Suggesting moderate levels of creativity across the board with respondents. To further analyze this data, I subdivided responses based on age and education levels. As can be seen below in figure 12, the spread of creativity in participants within the 19-24 age range appears to follow a normal distribution, with the majority of participants falling right in the middle.

There does seem to be a trend of older participants having more belief in their creative abilities, with individuals aged 25 to 34 representing the largest group in the 10/10 creativity level. The 45 to 54 range continues this trend, with the majority of participants in this age range also picking 10/10 for their creativity. This suggests that older participants likely have more experience to back up their level of confidence in their creation abilities.

Other demographic variables did not reveal any interesting trends or patterns and have been excluded from the main report. I do find it interesting to note that the creativity level does seem somewhat distributed across education levels; however, it seems that participants with a Bachelor's degree possess very high levels of confidence in their creative abilities, as can be seen in Figure 13 below.

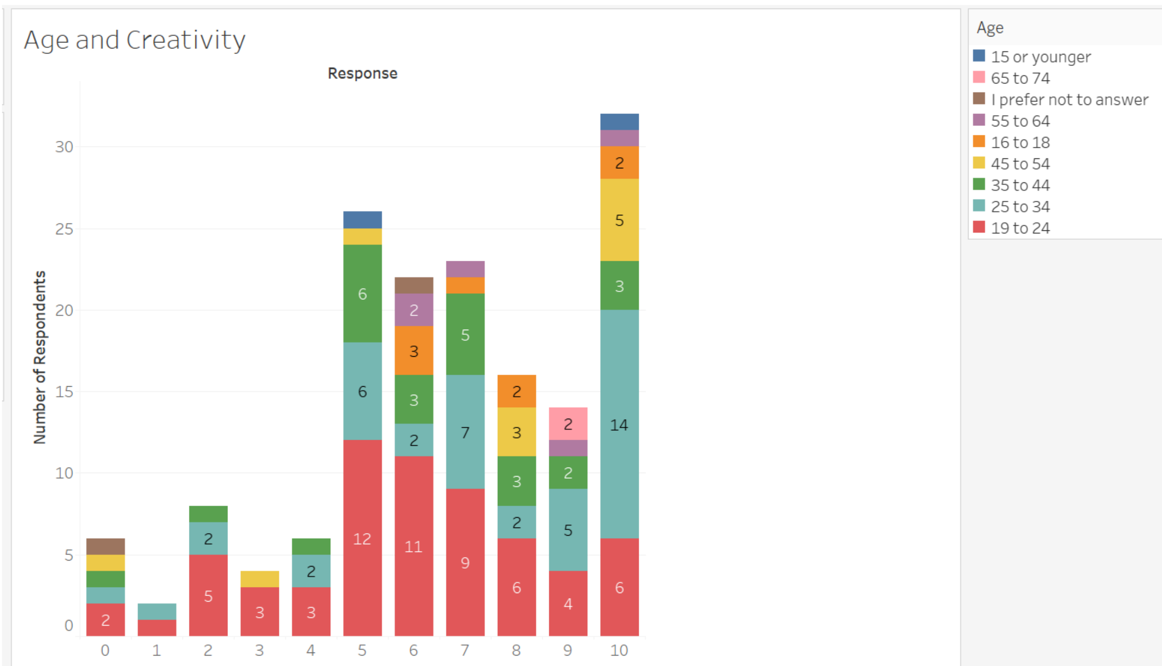



**Figure 12. Age demographic compared with creative abilities**

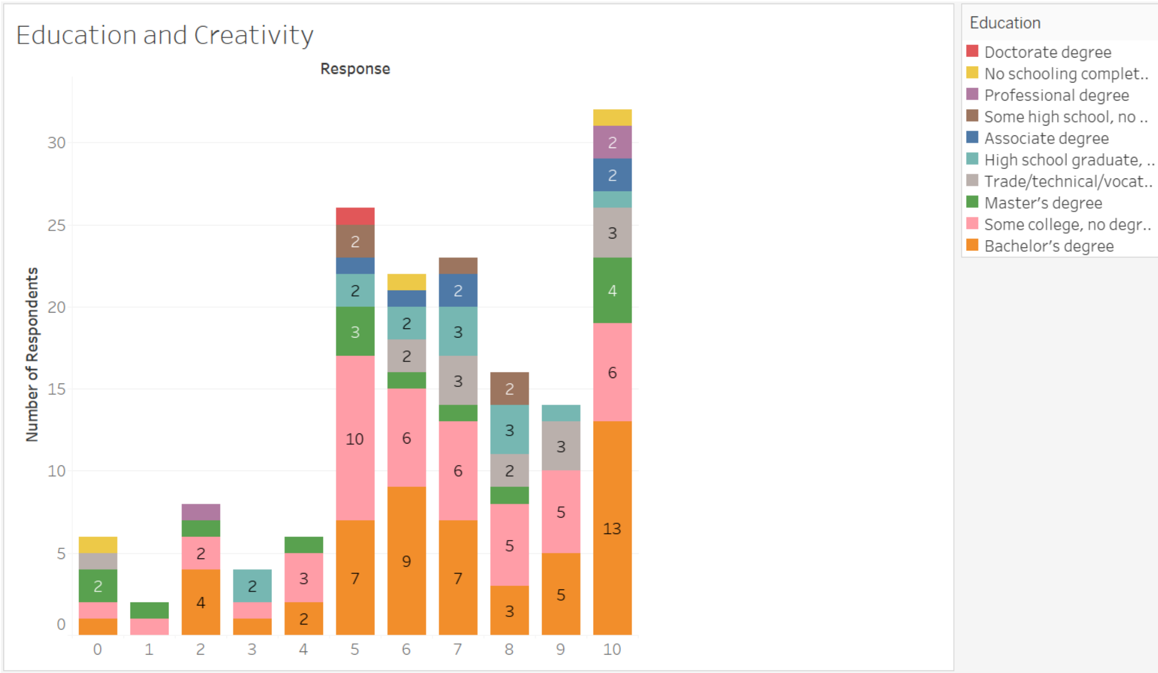



**Figure 13. Education demographic compared with creative abilities**

## 5.3 Time Commitment

Another important factor I evaluated was the level of time commitment participants are willing to devote to at-home manufacturing. Although the goal is to have the process of home manufacturing be as automated as possible, the machines used for at-home production will likely require monitoring and maintenance. As previously mentioned, apart from just making items with 3D printers or CNC machines, home manufacturers will likely have to take further steps to increase the value creation of their wares. This could be in the form of decoration, assembly, or hand finishing products.

All the activities described above will likely require some level of significant time commitment to the process. Participants were asked to select hourly time ranges they would be willing to work at their hypothetical home manufacturing jobs. The majority of participants answered that they would be willing to put in 3-5 hours per week. 6-10 hours was also a common response. As the time commitment levels increased, fewer participants were willing to engage in home manufacturing; however, a good number of respondents were willing to put in 31+ hours of work, as can be seen below in the figures.

Responses were subdivided by demographics for further analysis and pattern recognition. As can be seen below in Figure 14, Bachelor's degree holders show a clear consistent decline in willingness to participate in at-home manufacturing as the number of hours of time commitment increases. A similar trend can be observed with Master's Degree holders. Participants who have some college or are currently in college do seem to show a wide range of time commitment willingness; however, this spread leans heavier in the lower hours range. Participants with Associate degrees and participants with Trade certifications seem to have a higher inclination towards longer work hours in manufacturing from home jobs.

From the data in Figure 15, it can be argued that younger participants were willing to put less time into manufacturing from home; however, this trend is not so clear-cut. In terms of income level and time commitment, the pattern is also not as clear; however, it can be argued that lower-income individuals earning $1 - 24,999 are skewed towards the lower end of time commitment. The majority of the people willing to put in 31+ hours of work are earning

$50,000- $74,999 per annum. The second-largest 31+ hour group earns $25,000- $49,999 per annum.

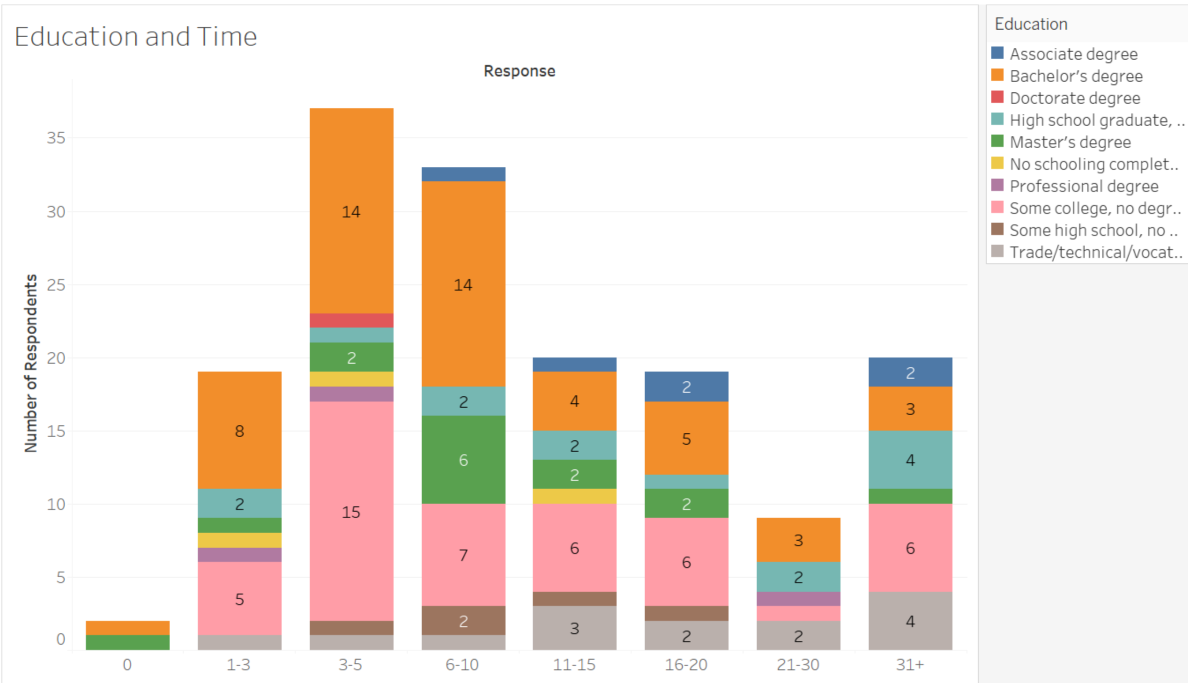



**Figure 14. Education demographic compared with time commitment**

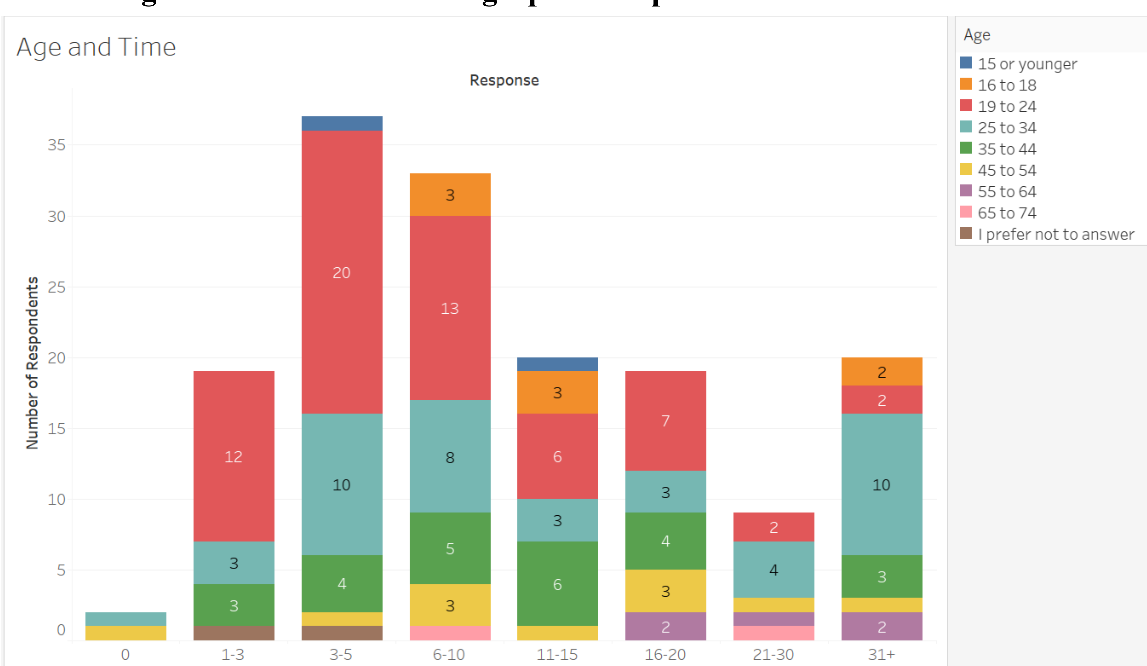



**Figure 15. Age demographic compared with time commitment**


**Figure 16. Income demographic compared with time commitment**

## 5.4 Printer Ownership

As previously discussed in the literature review, the issue of equipment ownership could render our manufacturing from home systems unviable due to issues with the profit allocation in the revenue model. To address this concern, I wanted to find out how many people owned 3D printers or had access to such machines. The results of this survey question can be seen in Figure 17 below. Interestingly, 35.2 % of respondents owned a 3D printer and 10.7% had frequent access to 3D printers and CNC machines. 17.6% of participants had used a 3D printer or CNC machine at least once, while 23.9% responded that they were familiar with the basic concepts of the process.

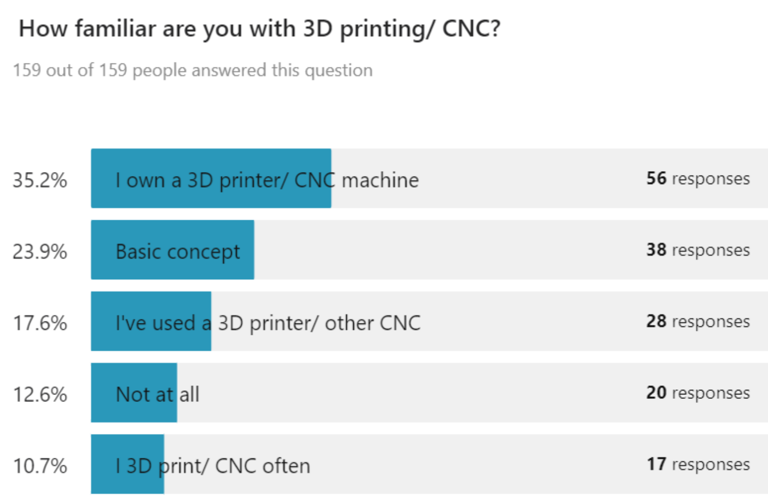



**Figure 17. Participants' level of creativity**

As usual, demographic segmentation was performed and the results analyzed. To my surprise, there seemed to be no demographic relationships with 3D printing exposure. Proportionally each demographic seemed to have an almost equal number of responses for each category when comparing age, education, and even income levels. This data suggests that 3D printer ownership may be a result of an innate interest in the technology and not related to a person's background.

Although in the income category, proportionally the largest groups owning printers are earning between $50,000 - $74,999 and $75,000 - $99,000, there is still a good distribution of individuals in other income brackets in the 3D printer owners/ regular access groups. This data suggests that if someone really wanted a 3D printer, they would get one regardless of age, education, or even income. This means that 3D printer ownership might be less of a barrier to entry than previously imagined. The results of the demographic segmentation can be seen below in Figures 18-20.

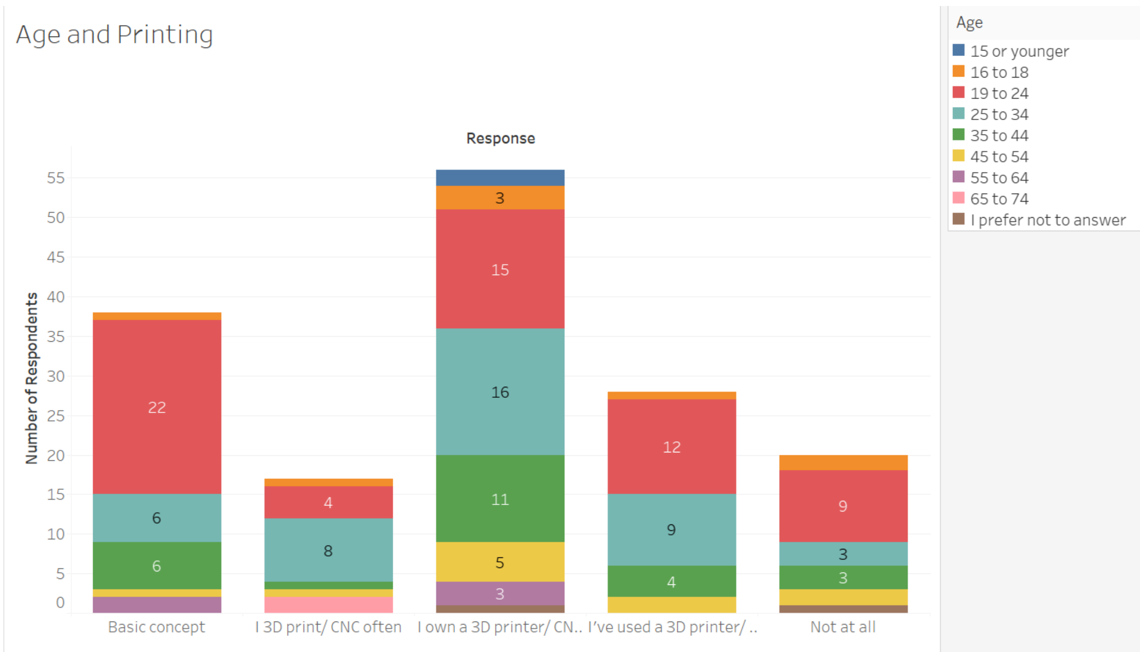



**Figure 18. Age demographic compared with printer familiarity**

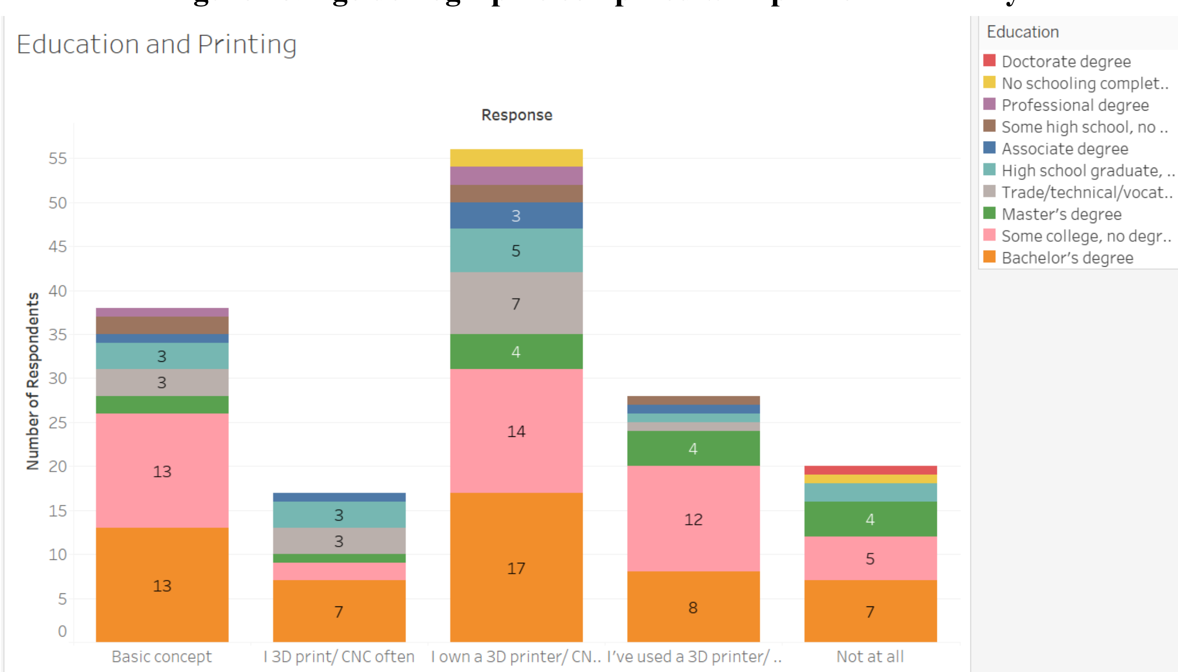



**Figure 19. Education demographic compared with printer familiarity**

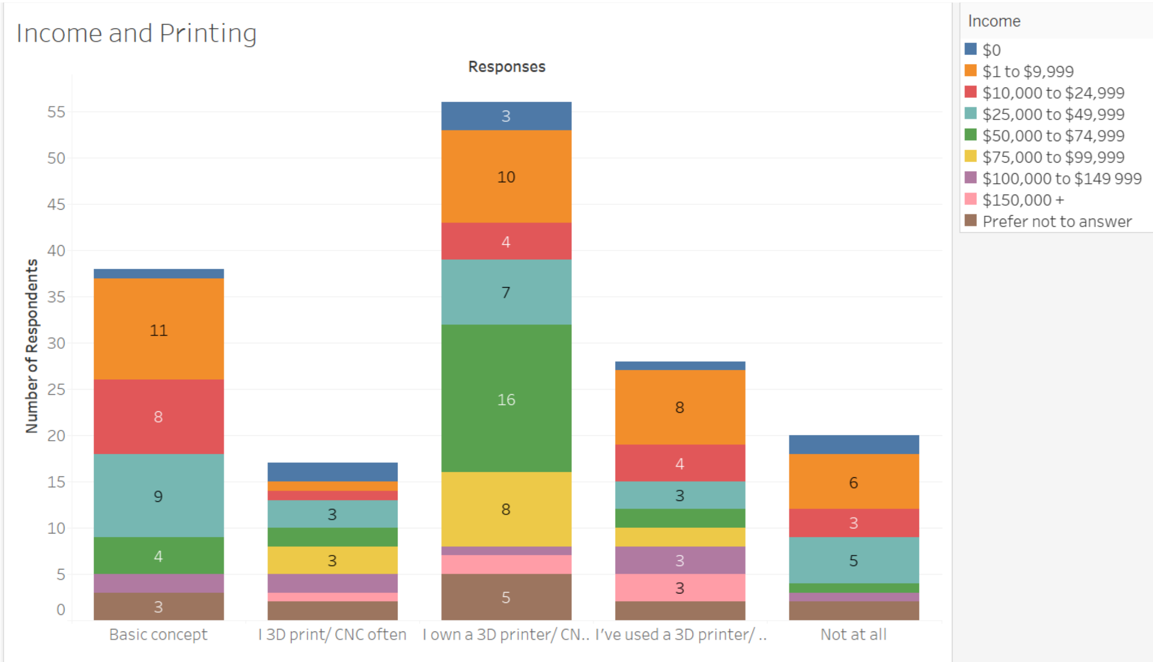



**Figure 20. Income demographic compared with printer familiarity**

## 5.5 Interest in Making

The previous sections of my findings were aimed at analyzing the level of preparedness an individual possesses to take on a manufacturing-from-home job. A goal of this project was also to analyze the levels of interest in at-home manufacturing as well as getting feedback on items people envision themselves manufacturing for their job. As can be seen below in Figure 21, on a scale of 1- 10 the average level of interest sits at 7.3/10. This suggests moderately high levels of interest in manufacturing from home as a job. 36.5% of respondents reported the highest level of interest at 10/10, while 18.2% reported they were willing to try, with a rating of 5/10. Most other participants fell somewhere in the middle.

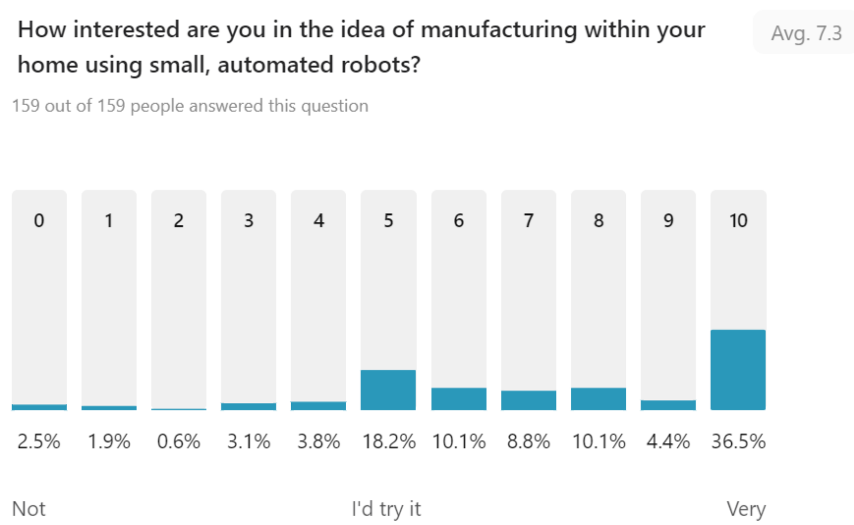



**Figure 21. Participants' level of interest**

Apart from levels of interest, the literature I had reviewed inspired curiosity in discovering what specific items people were interested in making. A list of possible item classes were presented and participants could select multiple choices and even suggest items.

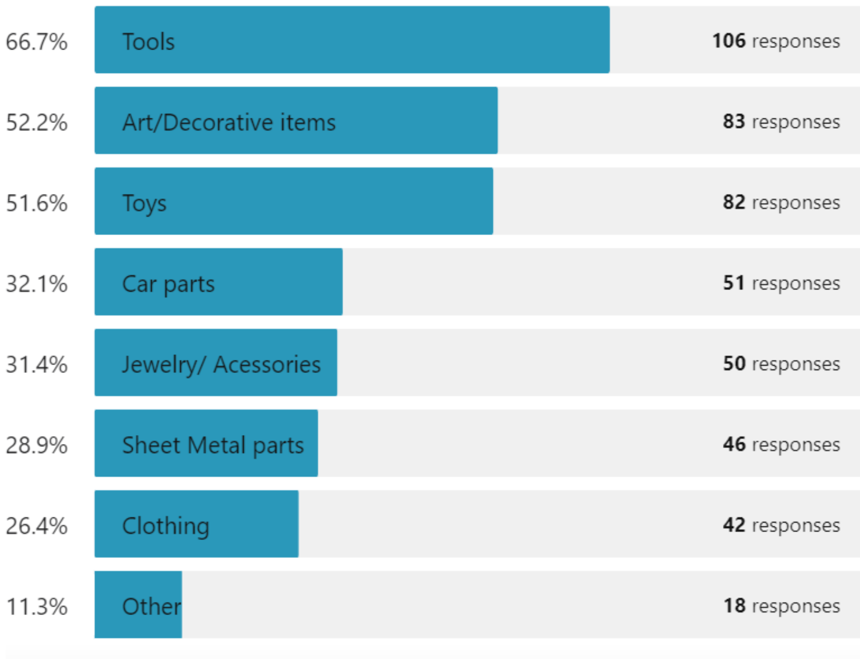



**Figure 22. Item's participants are interested in making**

The top category selected was tools. People were also particularly interested in art/ decorative items as well as toys. Other suggestions for manufacturing included prototyping, learning aids, robots, furniture, and kitchen utensils. This set of ideas seems very similar to that generated by the researchers cited in the literature review; however, I believe that because this was framed in the context of 3D printing at home as a job, I think the responses given were more realistic and true to form in terms of what is capable of being manufactured from home.

In the instance of interest in manufacturing, the trends across demographics did not seem very apparent due to the nature of the distribution of the data. As can be seen in Figure 23, there is a good spread of education levels across interest levels. I did note; however, that individuals with trade qualifications did seem to have a proportionally higher interest in home manufacturing as compared to other groups. When it came to income there was also a good spread; however, individuals earning $50,000- $74,999 seemed to have particularly high interest in manufacturing from home jobs. In the age category, the interest is also spread. The interesting data point in this demographic is that of individuals aged 55- 64 who all answered 10 for their interest level. After cross-referencing this demographic with the printer ownership data, this result makes sense as almost all respondents 55-64 already owned a 3D printer.

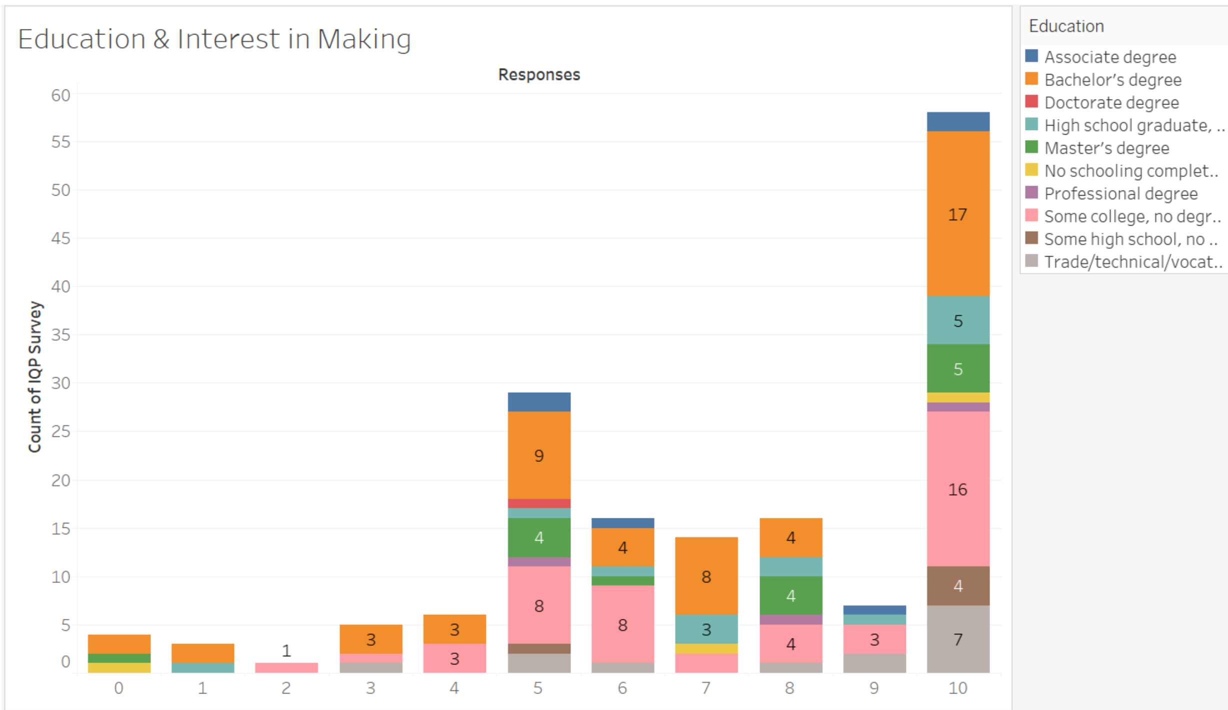



**Figure 23. Education demographic compared with interest in making**

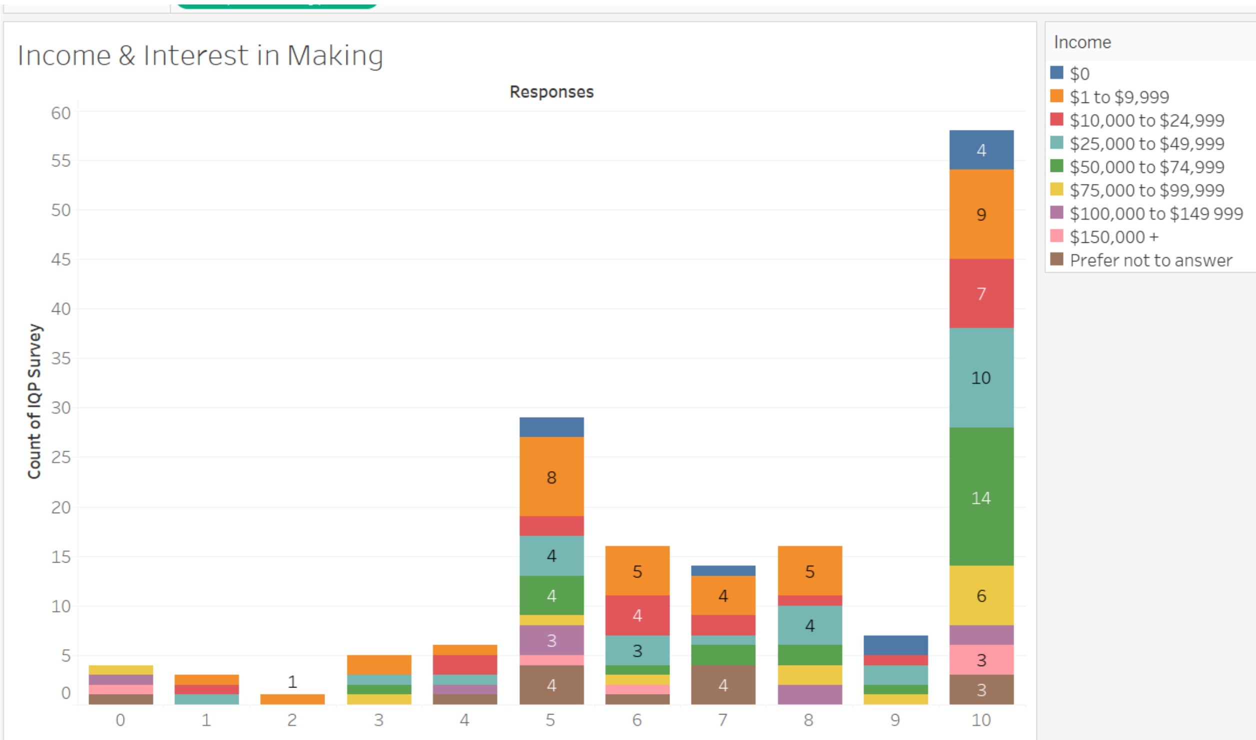



**Figure 24. Income demographic compared with interest in making**

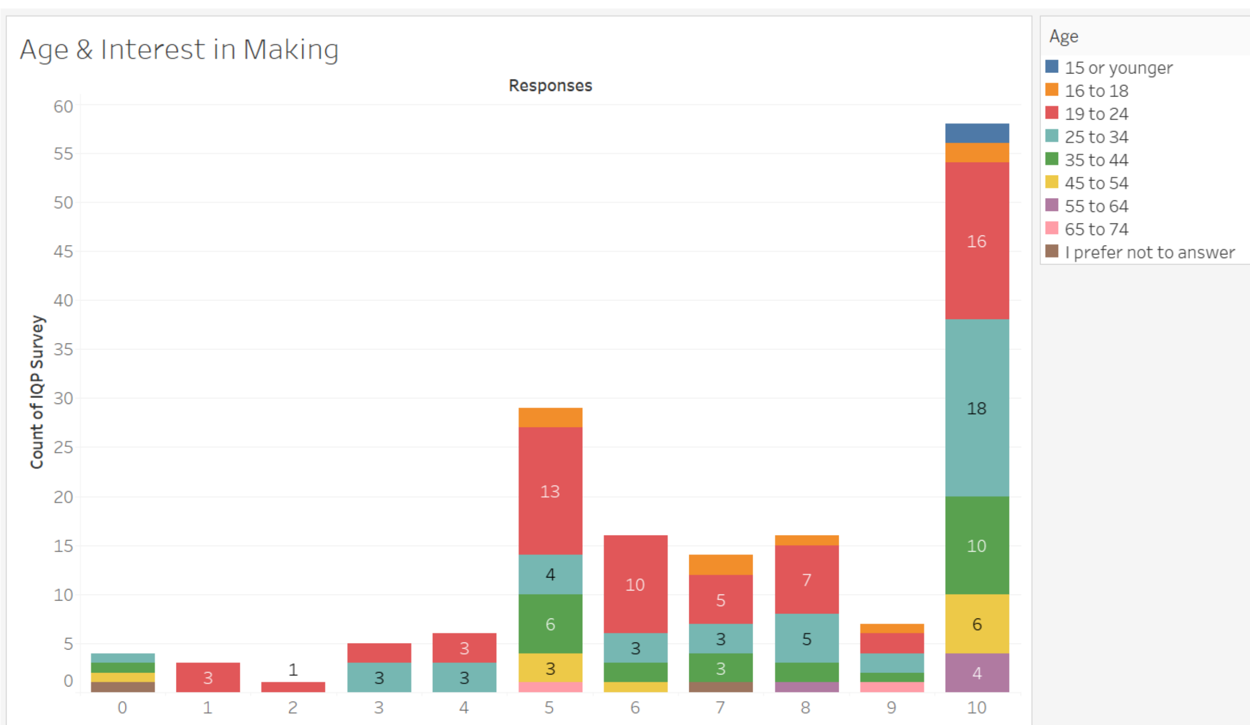



**Figure 25. Age demographic compared with interest in making**

## 5.6 Other Considerations

Apart from the data analyzed above, I also collected some data on various other minor details. For example, the participants' comfort levels using hand tools. The results of this can be seen below in Figure 26. The average is rather high, at 8.3. For this reason, I did not include analysis into demographics because the majority of survey takers were okay using hand tools.

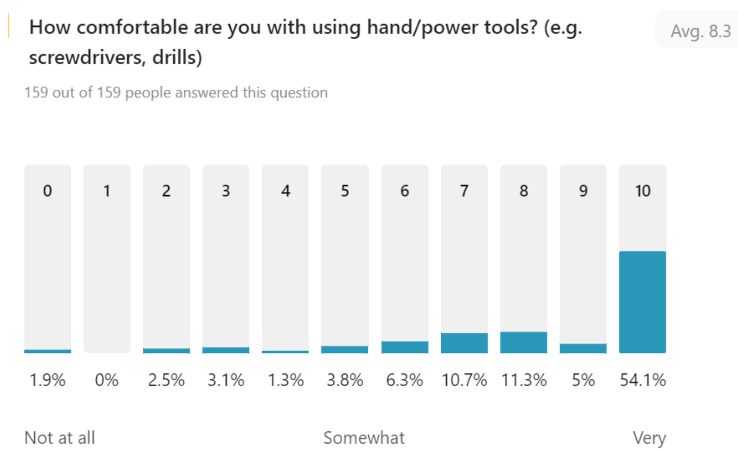



**Figure 26. Participants' level of comfort with hand tools**

I also considered space requirements for manufacturing at home. Participants would need to be able to house a small machine as pictured in Question 17 of the survey (see Appendix). 87.4% of participants responded that they had enough space, 10.1% said it would be a tight fit and only 2.5% of participants reported not having enough space for a small 3D printer/ laser cutter/ CNC machine as described in the image provided.

Although a bit of an odd question to ask in an online survey, I inquired about internet access and computer ownership. 100% of participants had regular internet access. 86.2% of participants owned a single laptop, 13.2% owned multiple laptops and only 0.6% did not own a laptop. In a work from home manufacturing environment; access to a computer and possibly multiple computers could be key to ensure smooth operation of the system.

Another consideration made was the number of other individuals living with a potential home manufacturer. The results of this can be seen below in Figure 27. On average each household has about 3 people living in it. This could be an advantage or a disadvantage. It could be advantageous to have others around to ensure safety and provide extra sets of hands whenever needed; however, having others around could lead to disruption and discomfort in everyday household activities with the sudden introduction of manufacturing activity within the home. Issues such as sound control and high electrical power draw could arise.

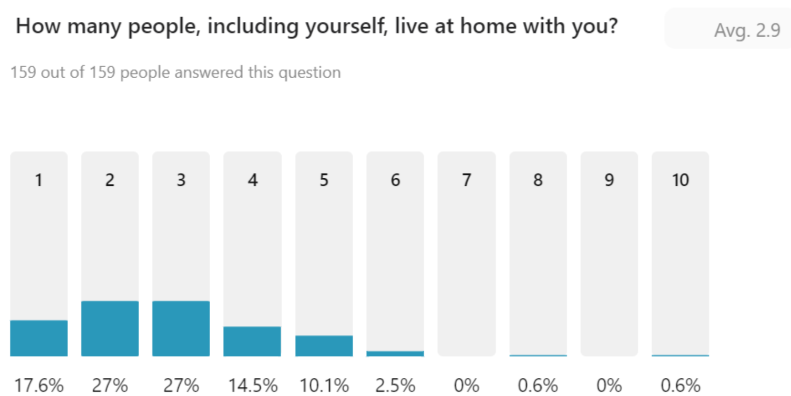



**Figure 27. Participants' household count**

One survey participant who actively engages in home production actually got in contact with me to share an example of experience dealing with difficulty arising from home based manufacturing. This participant had to spend over $3000 to obtain air filters and dust collectors for his house to ensure comfort for his family. This hidden cost in home maintenance could possibly create financial stress for lower income individuals and people who do not have access to credit. The participant also shared stories of difficulty managing fumes in his home when working with oil based varnishes or paint and also difficulty with general logistics of moving machinery and products around the house.

Another interesting idea which came up during conversation is the fact that individuals who have high probability of successfully manufacturing from home probably also have high levels of other skills; which make them equally suited for more traditional work roles which will likely provide much higher levels of income as compared to home manufacturing, and it might not be worth the time focusing energy on home manufacturing when this time could be devoted towards another higher paying job.

# 6. Conclusions and Recommendations

From the data gathered, it is clear that there is interest in the concept of home-based manufacturing with 3D printers and other automated machines as a means of providing income for the individual. However, due to limitations in volume, the cheap price of purchasing items traditionally manufactured, as well as the convenience and variety created with online shopping, it is unlikely home-based manufacturing will be a successful model for creating and selling everyday consumer items.

As discussed extensively in the literature review, to balance out the economics of a home-based manufacturing system, the goods produced have to be low volume and represent a high value to the intended consumer. Items such as medical devices, prosthetics, and spare parts could be potential items manufactured from home due to the lower volume requirement, the on-demand nature of 3D printing, as well as the unlimited customizability of 3D printing. Producing these kinds of items using 3D printing leverages the unique value proposition the technology brings to the table, compared to other traditional forms of manufacturing.

As previously mentioned, adding extra value to plastic printed parts or laser cut sheets will likely take some considerable amount of time, and so it is likely that individuals engaging in home-based manufacturing will need to be able to dedicate this time to the process. This might mean that it might only be viable for an individual to perform home manufacturing work if they have other stay-at-home work or a partner who will provide additional income. This ties back to the issue of value capture, as it is unlikely that a fully committed stay-at-home manufacturer will be earning a very high income, and so other forms of supplemental income will likely be required.

Although the data collected shows that there is a good distribution of 3D printer owners across all income groups, I believe that the initial start-up cost, as well as possible hidden costs associated with setting up a home-based manufacturing environment, might present financial trouble for lower-income individuals and those without access to credit. This is why a key suggestion for the implementation of this system is the creation of a government-sponsored program for at-home manufacturing. This will likely stimulate the economy and also reduce the pressure of profitability on the ecosystem as a whole because the government will provide capital and be less concerned with the return on investment, but rather the growth and opportunity created through the implementation of a home-based manufacturing economy.

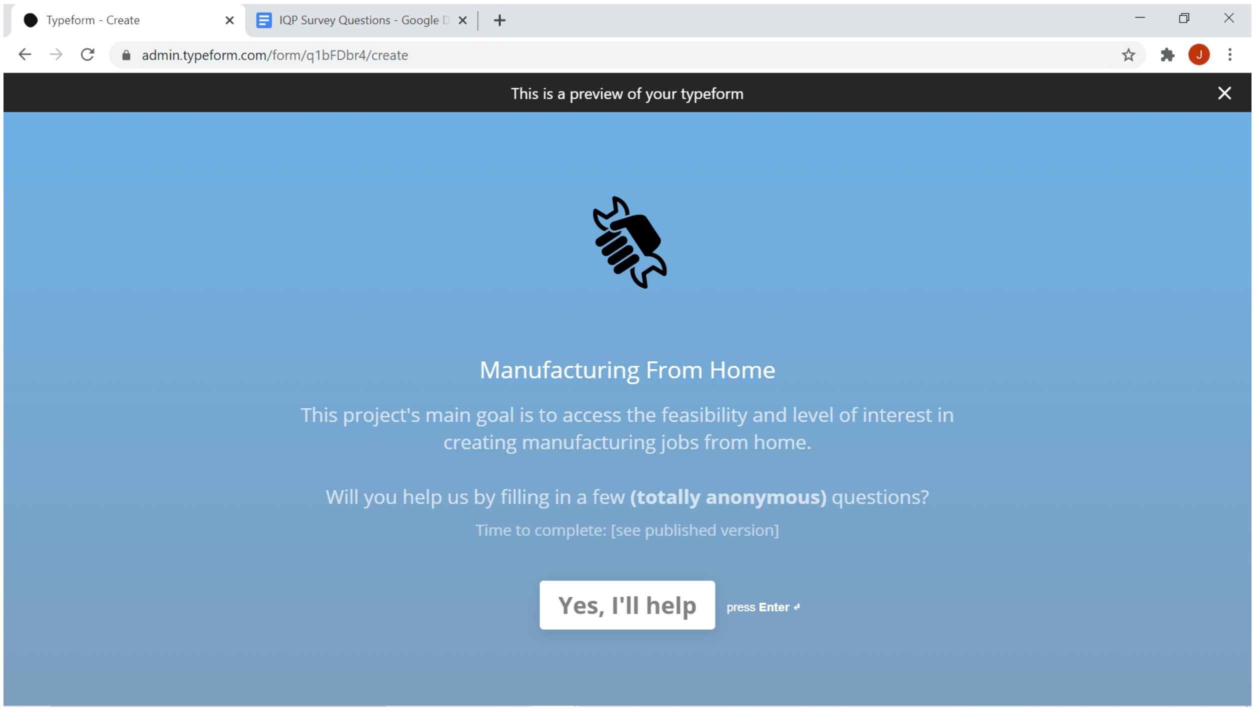
Participants in the hypothetical home-based manufacturing system will require extensive screening/ training to ensure adequate work conditions, safety as well as high standards of the finished product. There will need to be some sort of central organization or body charged with the maintenance of ethics and standards to prevent the corruption or decay of the system.

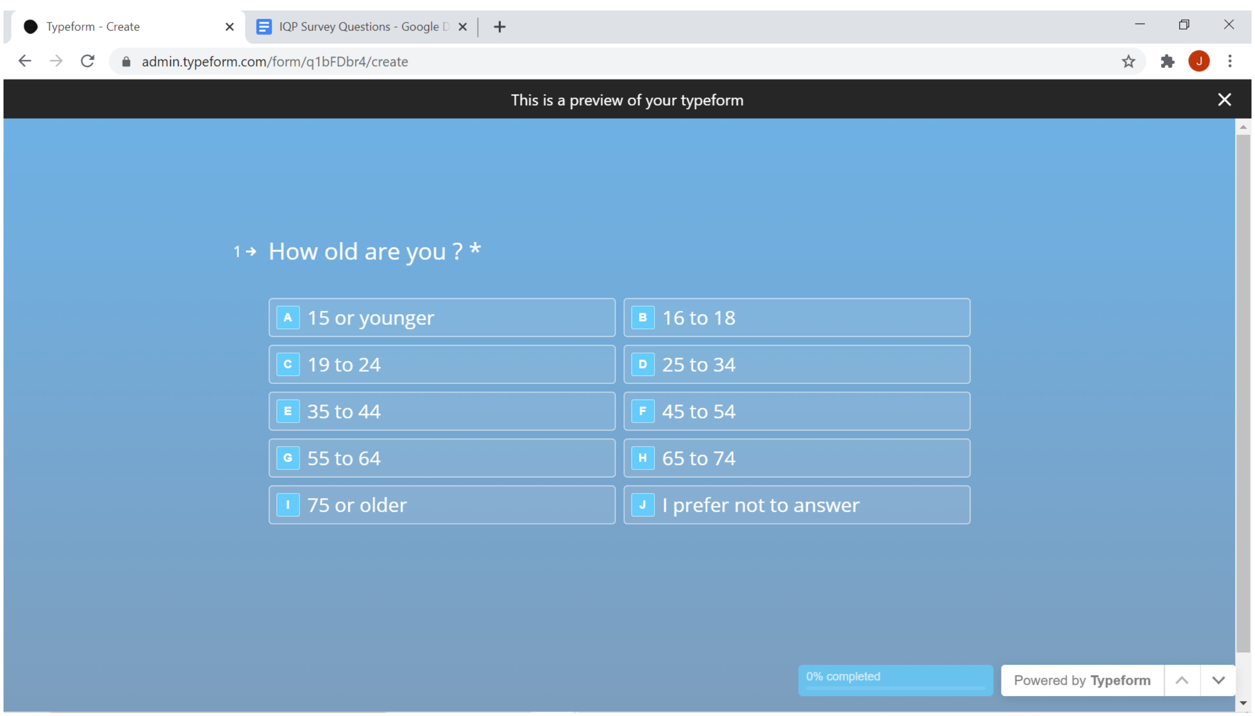
Although there is high interest in learning Computer-Aided Design software, the majority of CAD software is rather complicated and time-consuming to learn. The implementation of easy-to-use CAD tools and smartphone apps capable of generating 3D scans of objects will likely be a much-welcomed addition to the manufacturing-from-home ecosystem, as it will make the technology and process more accessible for individuals who might otherwise struggle.

From the research discussed in previous work, as well as the data I collected and analyzed, at home manufacturing is definitely a possibility; however, unless the issues raised in this paper are adequately handled (particularly the financial/economic issues), any implementation of a home-based manufacturing economy is likely to be successful without the adequate effort and planning suggested in this body of work.

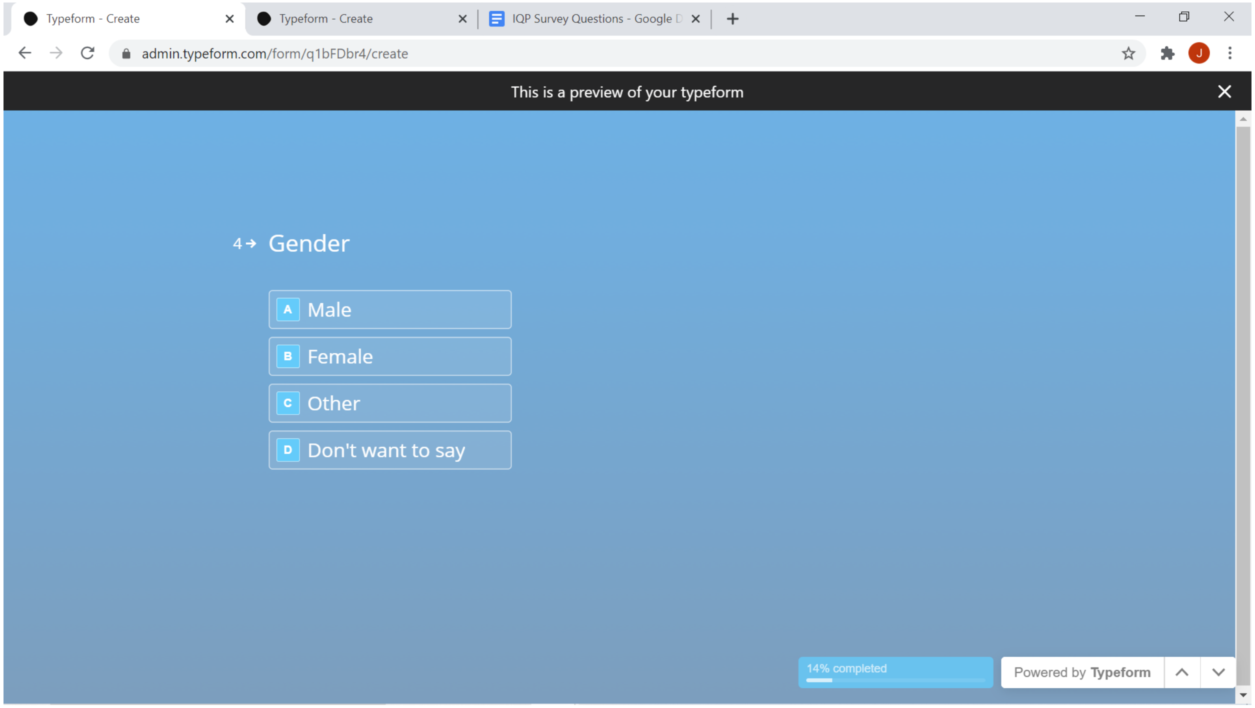
# 7. Appendix

## Survey Questions




**Questions 2- 3 Vary : Collecting info on Survey takers state or country. Text entry is dependent on answer to living or working in the United States**


Typeform - Create
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admin.typeform.com/form/q1bFDbr4/create
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4→ Gender
A Male
B Female
C Other
D Don't want to say
14% completed
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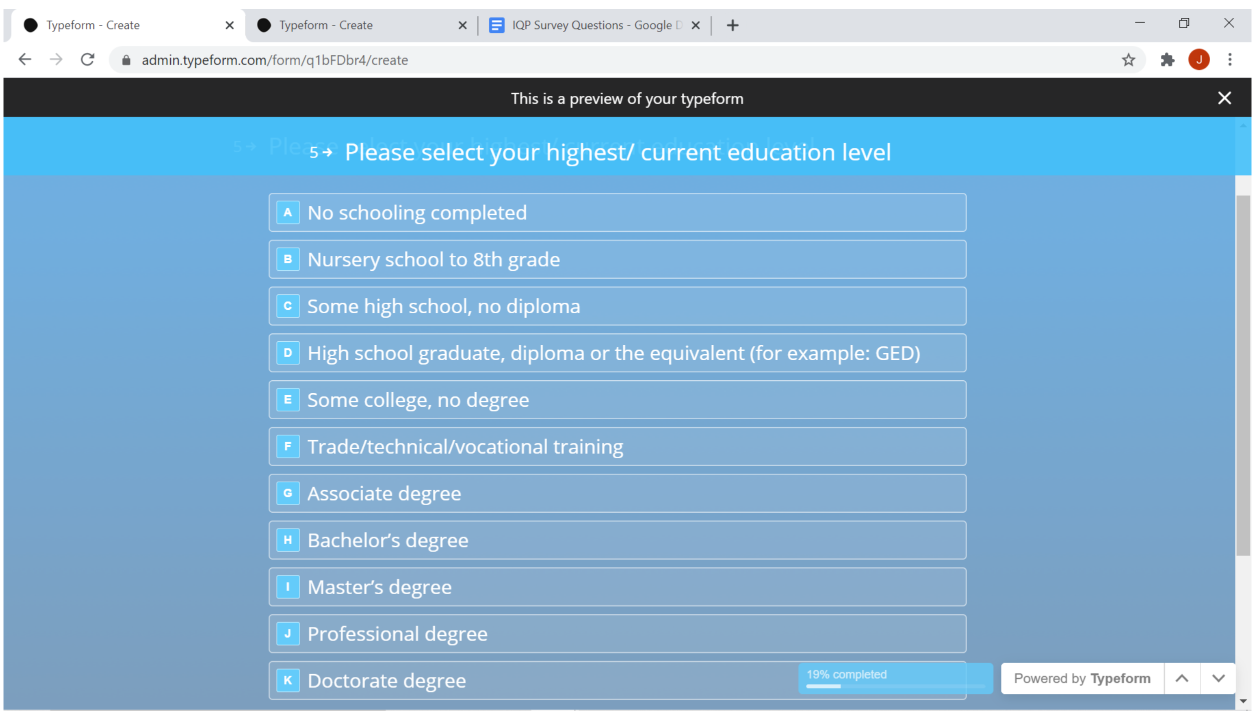
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5→ Please select your highest/ current education level
A No schooling completed
B Nursery school to 8th grade
C Some high school, no diploma
D High school graduate, diploma or the equivalent (for example: GED)
E Some college, no degree
F Trade/technical/vocational training
G Associate degree
H Bachelor's degree
I Master's degree
J Professional degree
K Doctorate degree
19% completed
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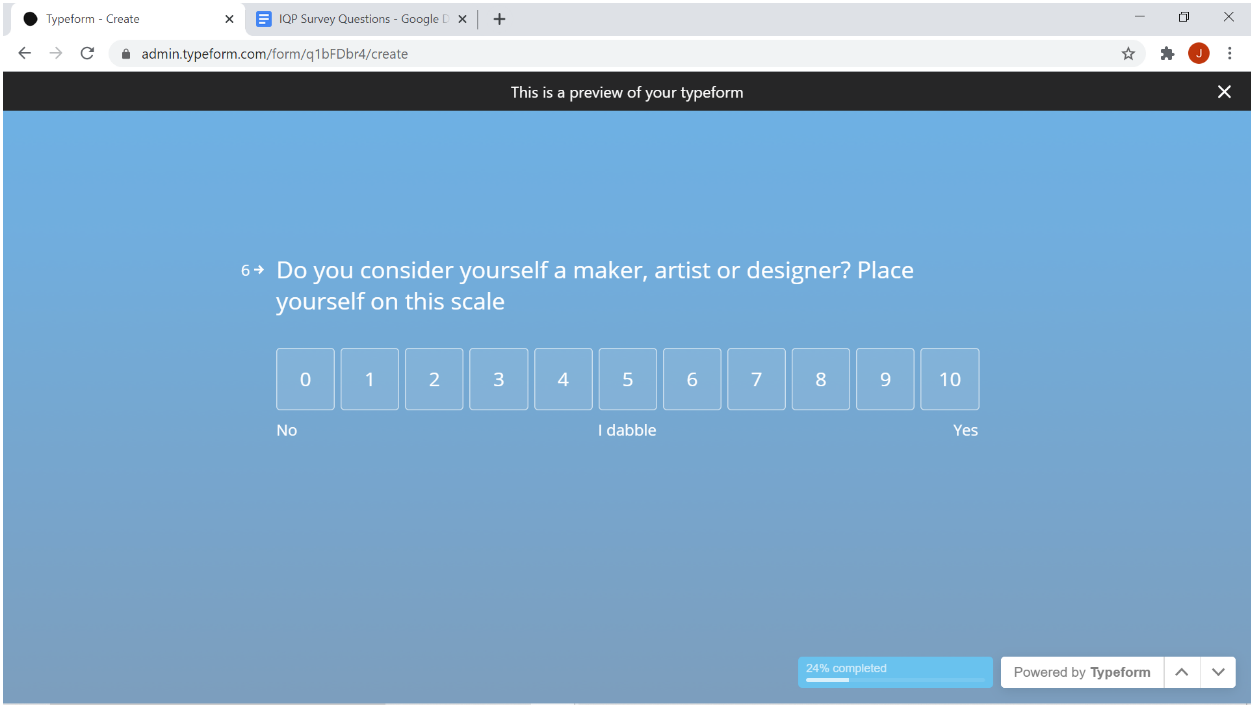
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This is a preview of your typeform
6→ Do you consider yourself a maker, artist or designer? Place yourself on this scale
0
1
2
3
4
5
6
7
8
9
10
No
I dabble
Yes
24% completed
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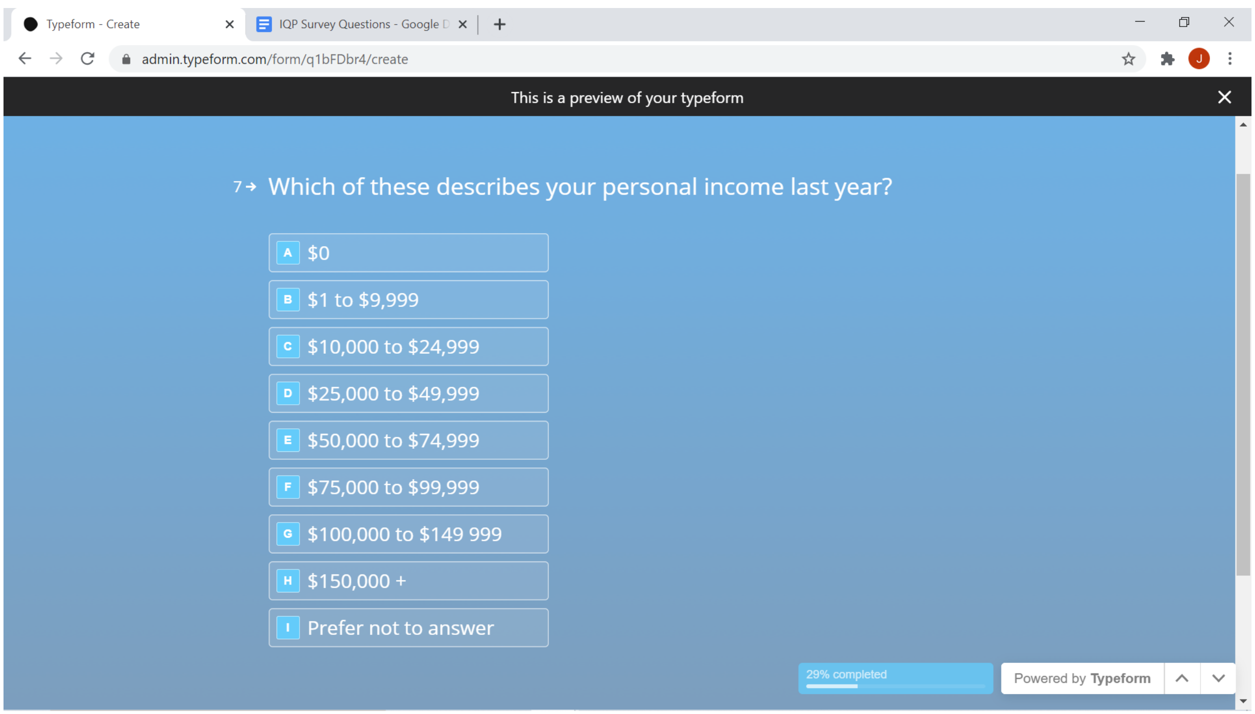
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admin.typeform.com/form/q1bFDbr4/create
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7→ Which of these describes your personal income last year?
A $0
B $1 to $9,999
C $10,000 to $24,999
D $25,000 to $49,999
E $50,000 to $74,999
F $75,000 to $99,999
G $100,000 to $149 999
H $150,000 +
I Prefer not to answer
29% completed
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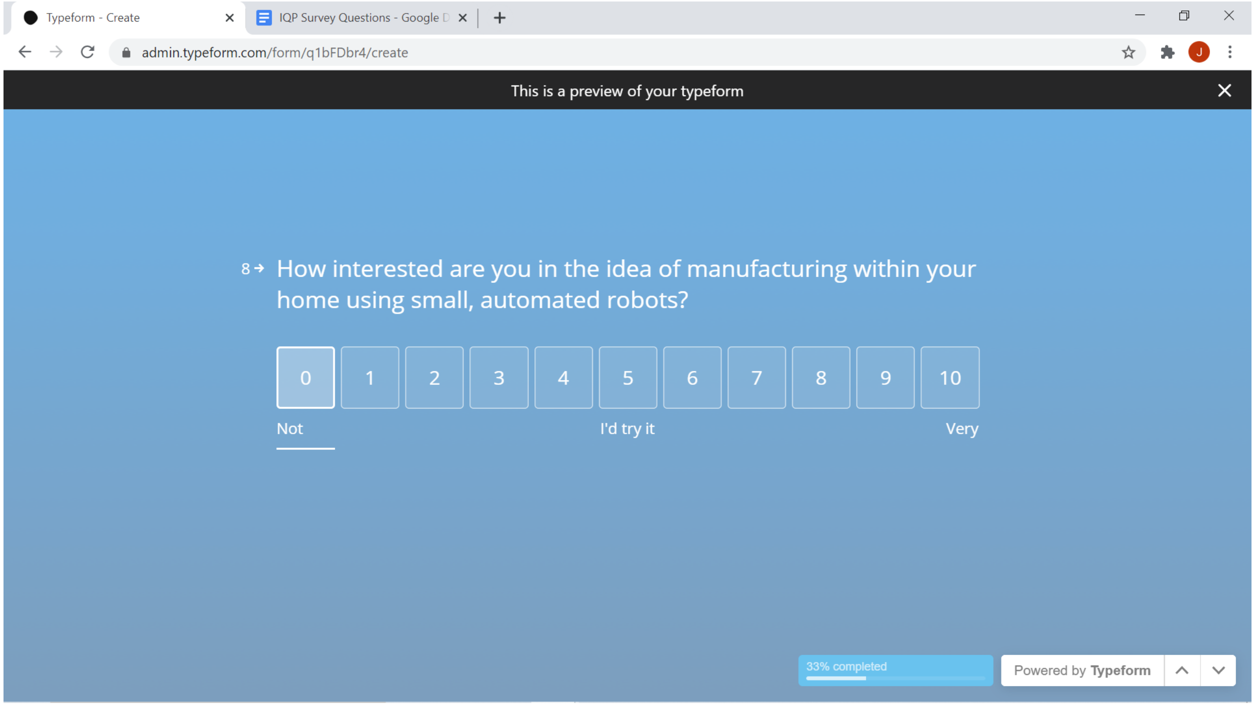
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8→ How interested are you in the idea of manufacturing within your home using small, automated robots?
0 1 2 3 4 5 6 7 8 9 10
Not
I'd try it
Very
33% completed
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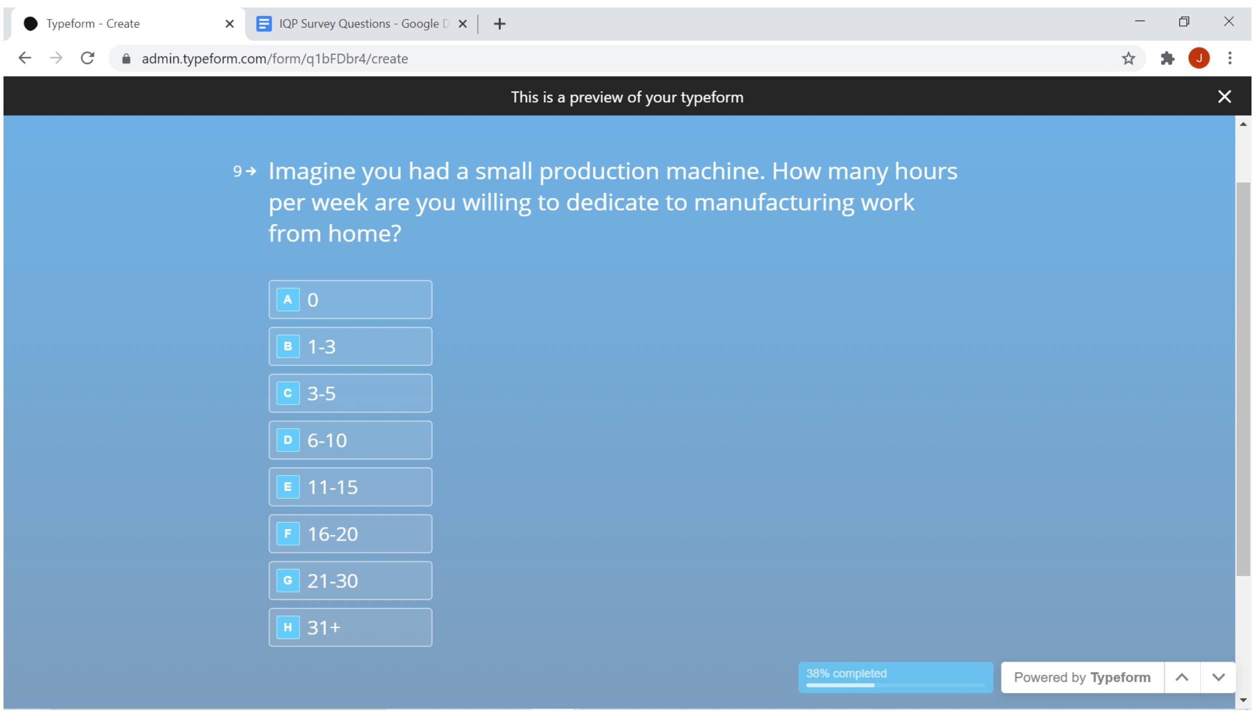
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9→ Imagine you had a small production machine. How many hours per week are you willing to dedicate to manufacturing work from home?
A 0
B 1-3
C 3-5
D 6-10
E 11-15
F 16-20
G 21-30
H 31+
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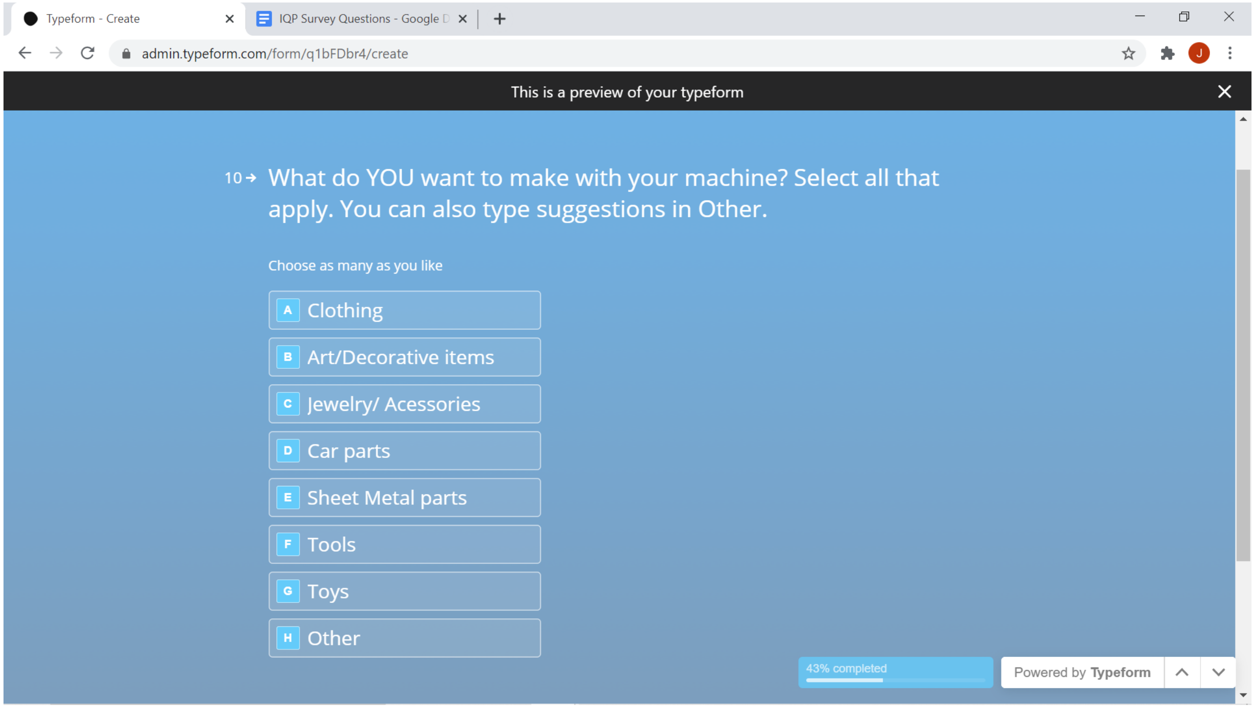
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This is a preview of your typeform
10→ What do YOU want to make with your machine? Select all that apply. You can also type suggestions in Other.
Choose as many as you like
A Clothing
B Art/Decorative items
C Jewelry/ Acessories
D Car parts
E Sheet Metal parts
F Tools
G Toys
H Other
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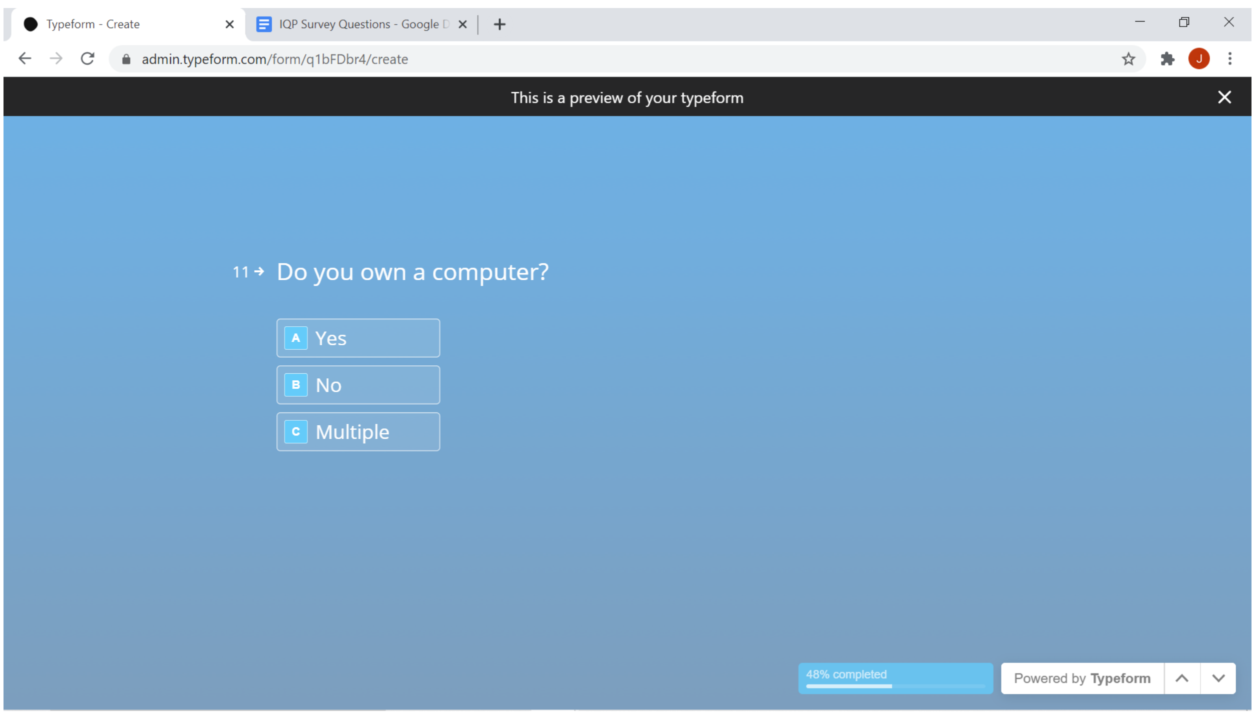
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This is a preview of your typeform
11→ Do you own a computer?
A Yes
B No
C Multiple
48% completed
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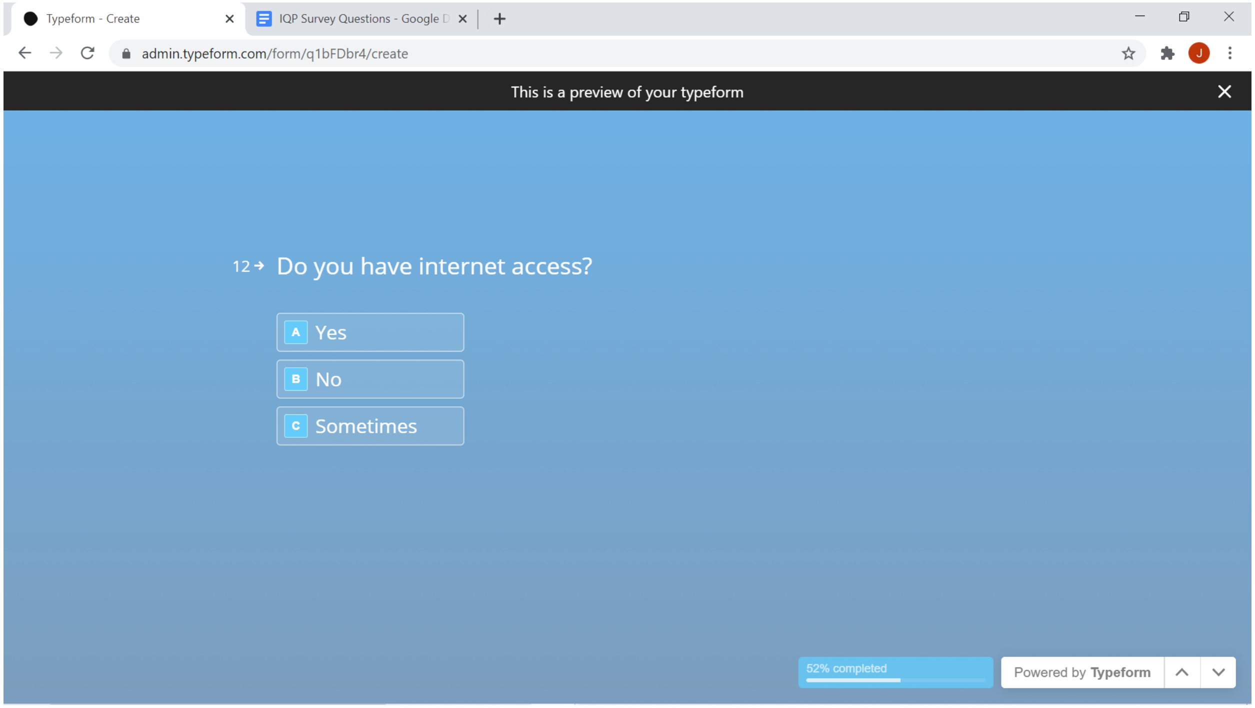
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12→ Do you have internet access?
A Yes
B No
C Sometimes
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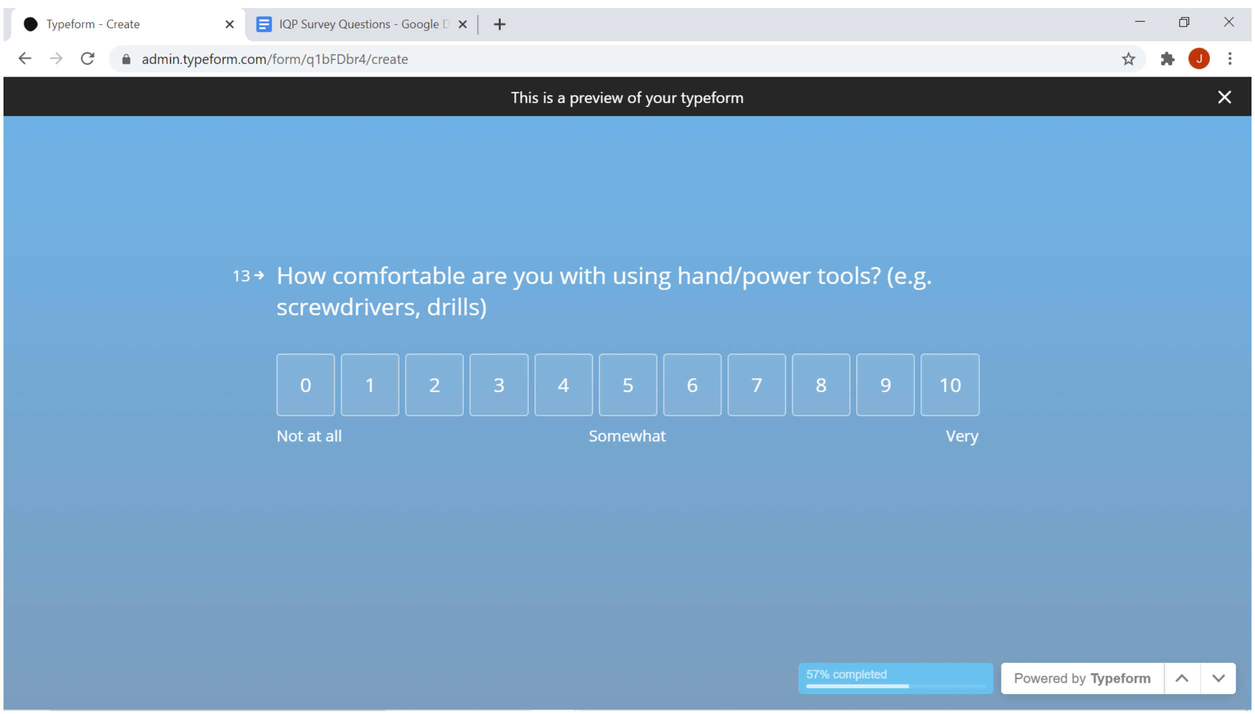
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IQP Survey Questions - Google D
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This is a preview of your typeform
13→ How comfortable are you with using hand/power tools? (e.g. screwdrivers, drills)
0 1 2 3 4 5 6 7 8 9 10
Not at all
Somewhat
Very
57% completed
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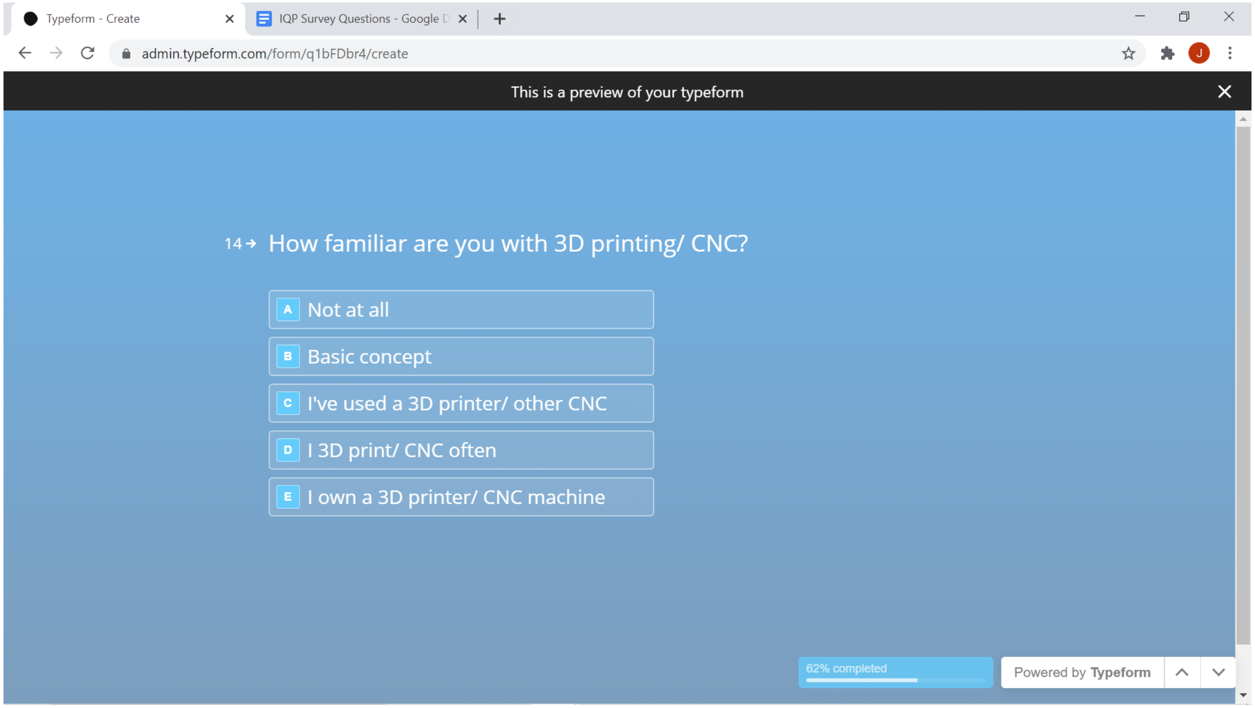
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This is a preview of your typeform
14→ How familiar are you with 3D printing/ CNC?
A Not at all
B Basic concept
C I've used a 3D printer/ other CNC
D I 3D print/ CNC often
E I own a 3D printer/ CNC machine
62% completed
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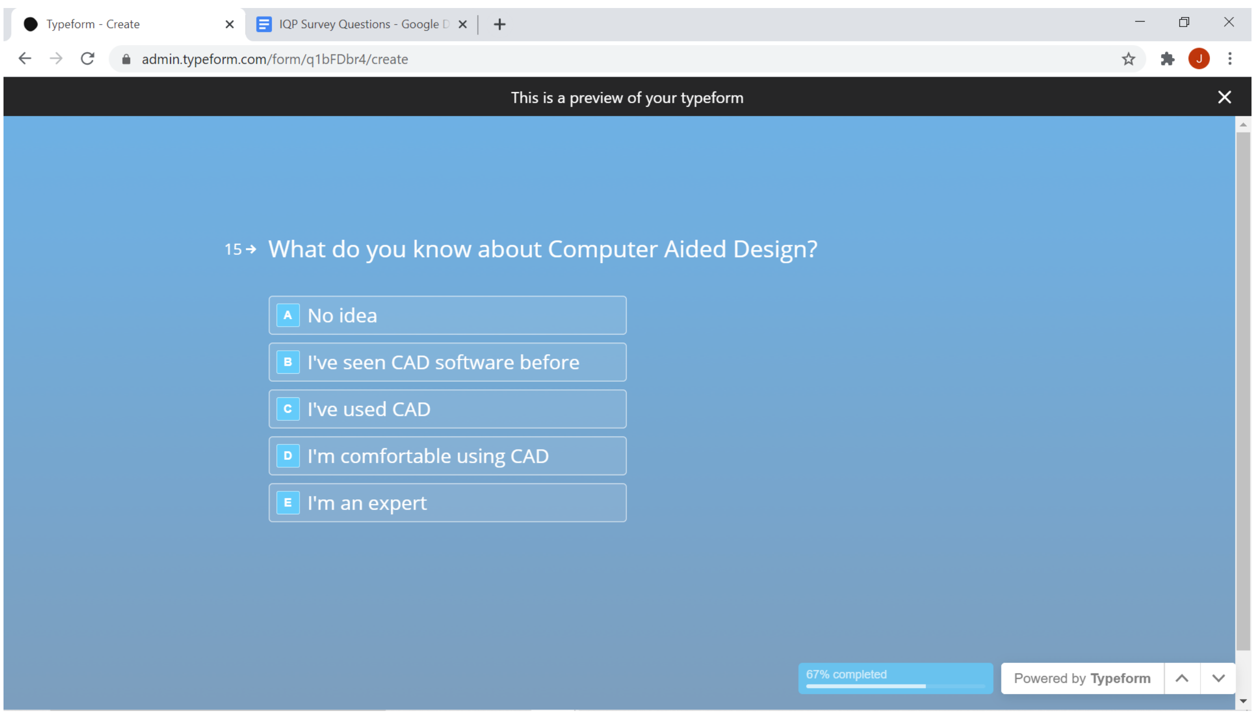
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IQP Survey Questions - Google D
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15→ What do you know about Computer Aided Design?
A No idea
B I've seen CAD software before
C I've used CAD
D I'm comfortable using CAD
E I'm an expert
67% completed
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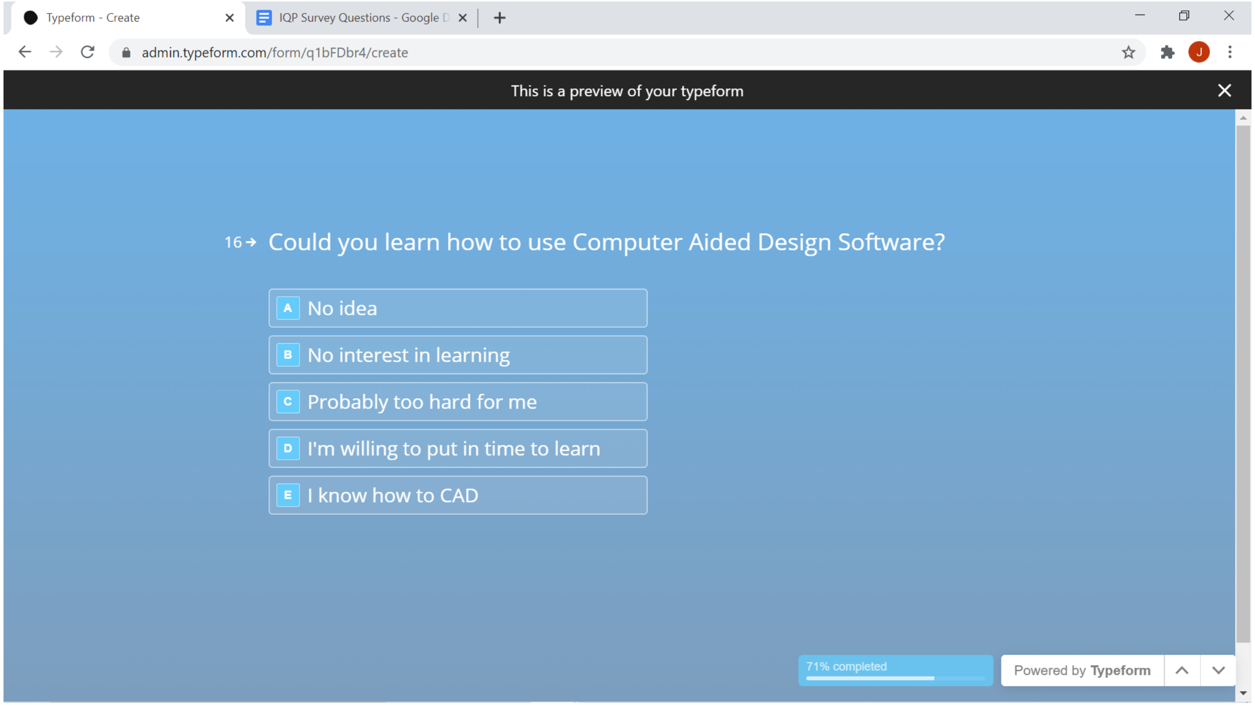
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This is a preview of your typeform
16→ Could you learn how to use Computer Aided Design Software?
A No idea
B No interest in learning
C Probably too hard for me
D I'm willing to put in time to learn
E I know how to CAD
71% completed
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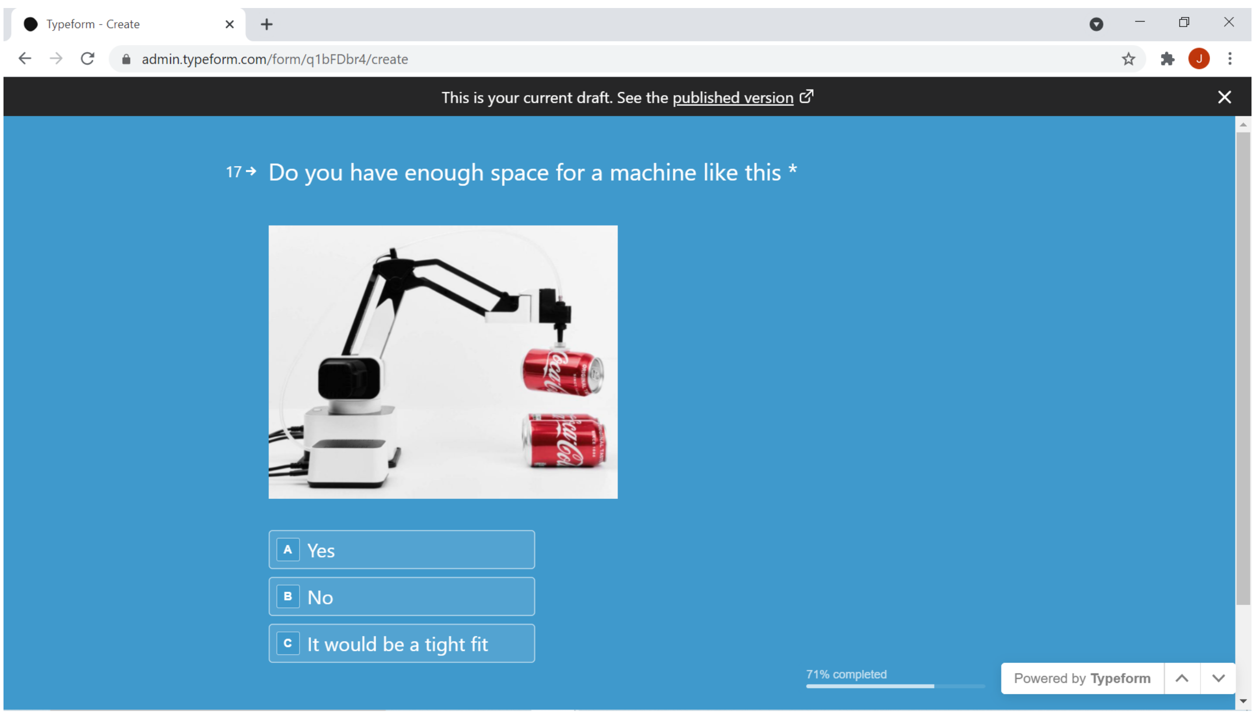
Typeform - Create
admin.typeform.com/form/q1bFDbr4/create
This is your current draft. See the published version
17→ Do you have enough space for a machine like this *
A Yes
B No
C It would be a tight fit
71% completed
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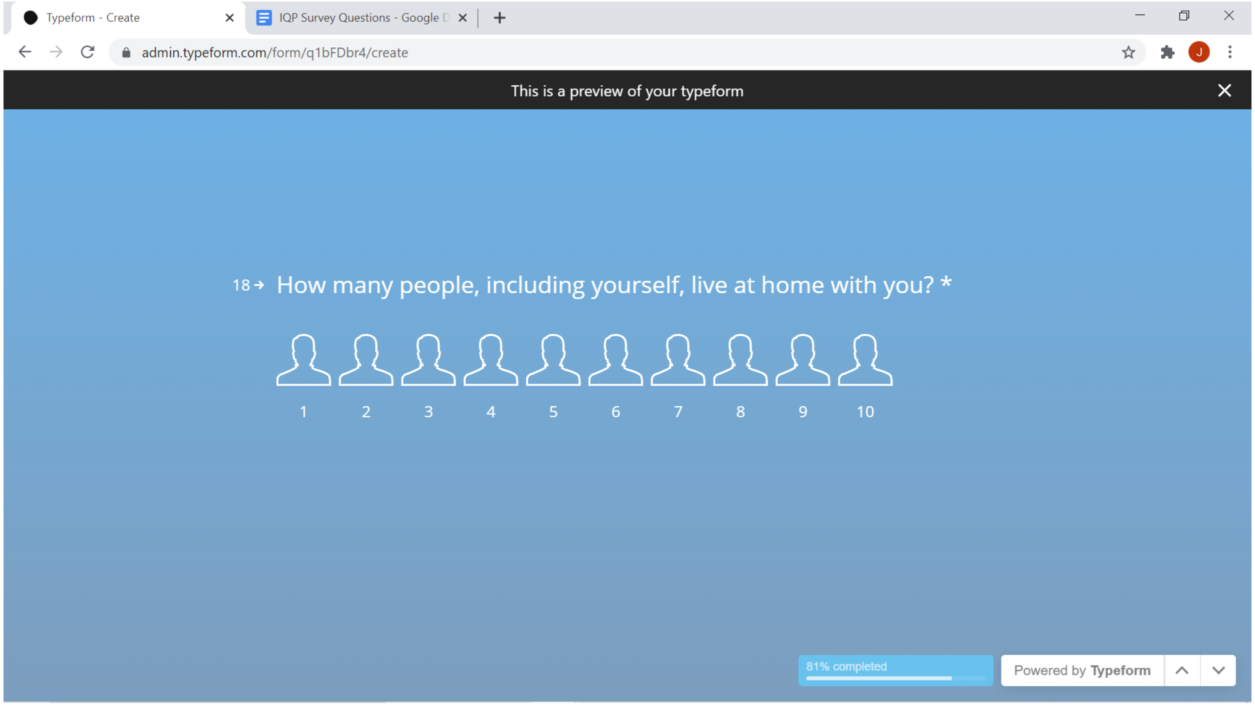
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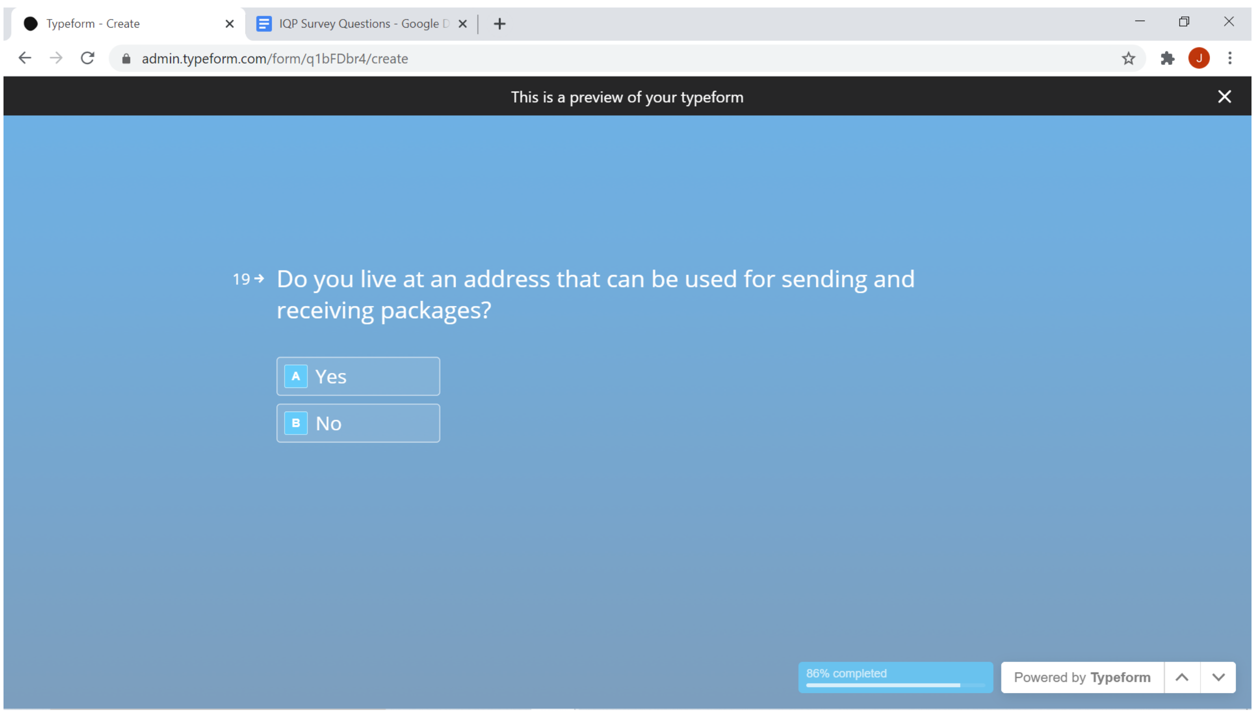
IQP Survey Questions - Google D
admin.typeform.com/form/q1bFDbr4/create
This is a preview of your typeform
18→ How many people, including yourself, live at home with you? *
1 2 3 4 5 6 7 8 9 10
81% completed
Powered by Typeform


Typeform - Create
IQP Survey Questions - Google D
admin.typeform.com/form/q1bFDbr4/create
This is a preview of your typeform
19→ Do you live at an address that can be used for sending and receiving packages?
A Yes
B No
86% completed
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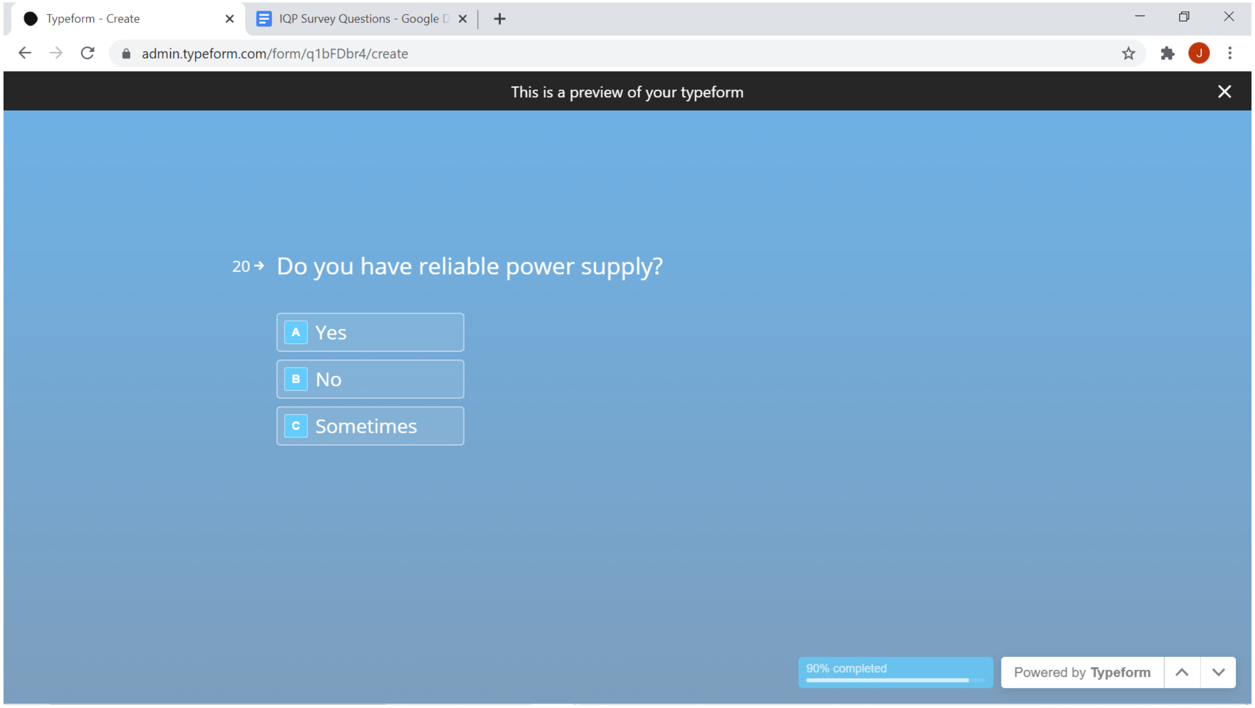
Typeform - Create
IQP Survey Questions - Google D
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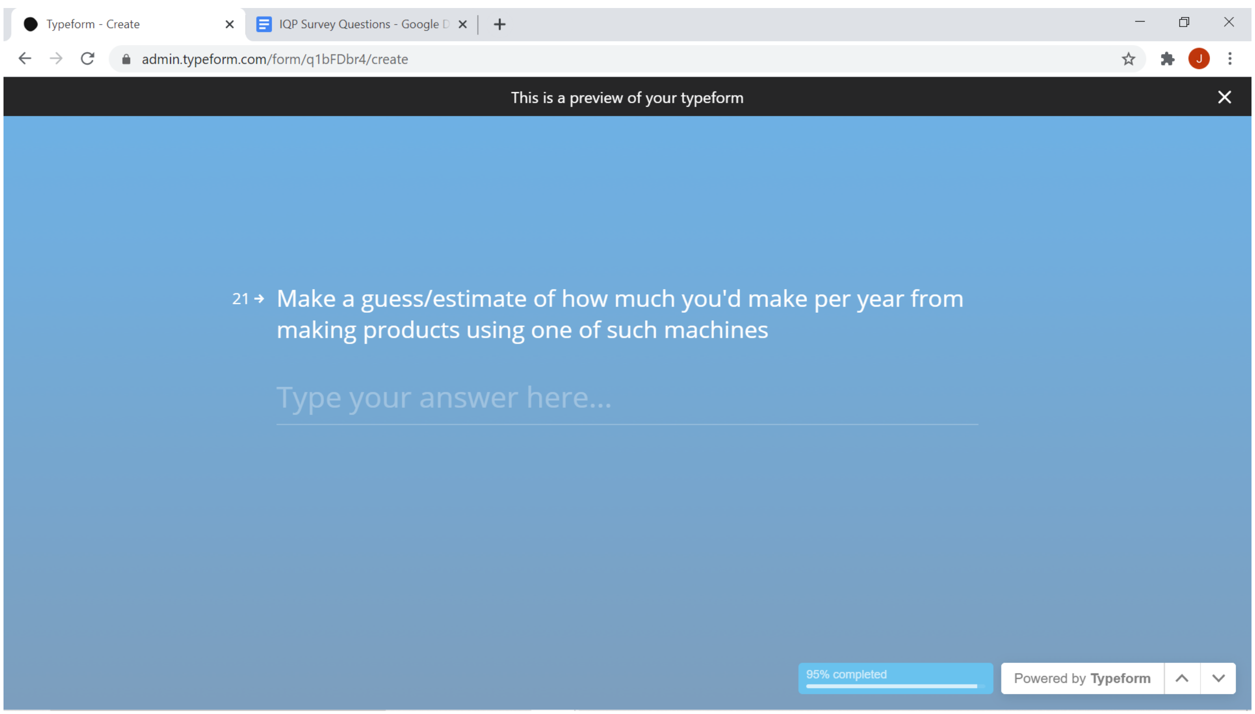
This is a preview of your typeform
20 → Do you have reliable power supply?
A Yes
B No
C Sometimes
90% completed
Powered by Typeform


Typeform - Create
IQP Survey Questions - Google D
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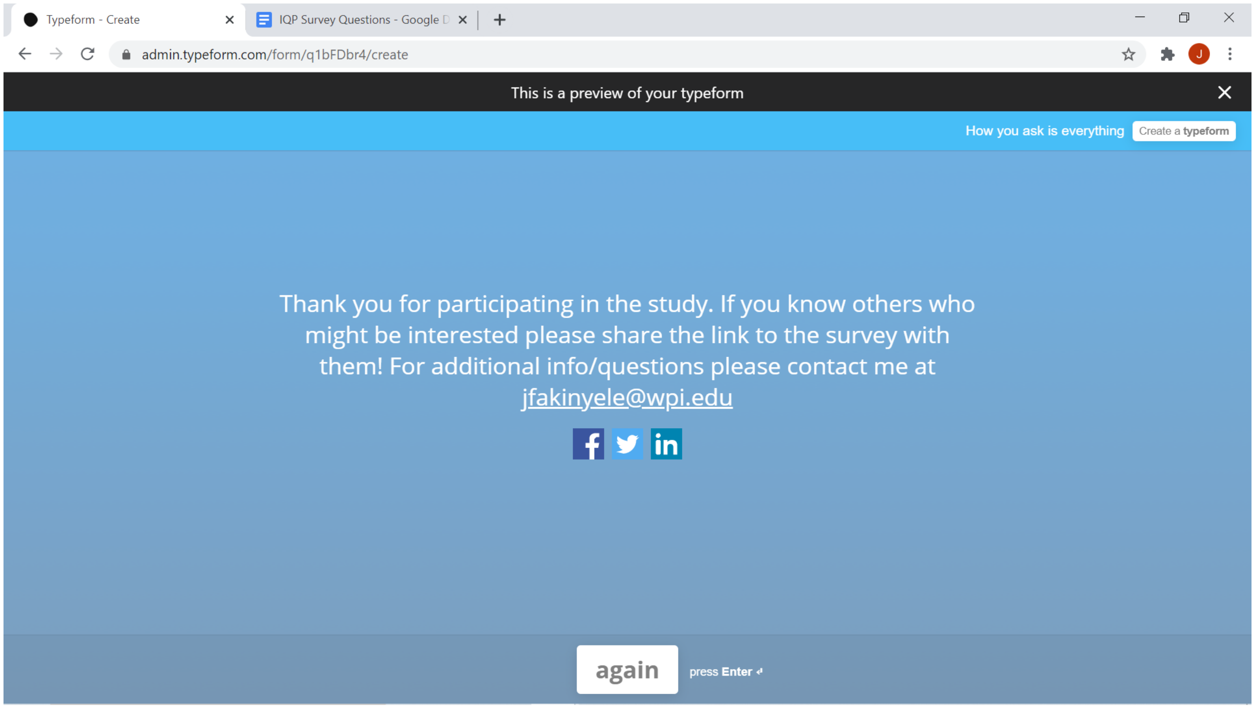
This is a preview of your typeform
21 → Make a guess/estimate of how much you'd make per year from making products using one of such machines
Type your answer here...
95% completed
Powered by Typeform




## Online Post

Hello! My name's Jesulona. I'm a Mechanical Engineering and Robotics Engineering student at WPI.
I'm conducting a study where I'll be developing a framework that will enable people to engage in manufacturing activities from home using automated systems (3D printers & CNC) with the end goal of bringing innovative products and services to the public.
I'm sure you'd love to make stuff yourself at home! To further my study, I need your help filling out this quick, anonymous, survey.
Thank you

https://tyh8khkv1kj.typeform.com/to/q1bFDbr4

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